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Digital Map Requirements Study in Support of Advanced Cockpit Moving Map Displays

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13. ABSTRACT *(Maximum 200 words)*

This report documents the results of a digital map requirements study that the Naval Research Laboratory (NRL) performed for the Tactical Aircraft Moving Map Capability (TAMMAC) Integrated Program Team (IPT) at NAVAIR (PMA 209) in August 1995. The objective of the study was to establish the map data requirements for a new digital moving map system being built for the F/A-18, AV-8B, AH-1W, UH-1N, V-22, and potentially other aircraft. A primary NAVAIR goal in specifying the new system was to enhance situational awareness (SA) and aircrew mission effectiveness, without further burdening pilot task workload. To ensure that the end-users' explicit map needs were considered, NRL investigators elicited one-on-one aircrew evaluations of a wide variety of map data types (both topographic and tactical) and map display parameters, including feature size, orientation, color, symbology, etc., to help define an optimum map design for cockpit displays. NRL presented these map variations as a series of 16 demonstrations (on a Silicon Graphics workstation) to 30 pilots and aircrew at the Naval Air Warfare Center in Pax River, MD.

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DIGITAL MAP REQUIREMENTS STUDY IN SUPPORT OF ADVANCED COCKPIT MOVING MAP DISPLAYS

1.0 INTRODUCTION

1.1 Objective

The objective of this project is to establish the map data requirements for a next-generation digital moving map system that will be designed for installation in the F/A-18, AV-8B, AH-1W, UH-1N, V-22, and potentially other aircraft. A primary Naval Air Systems Command (NAVAIR) goal in specifying the new system is to enhance situational awareness (SA) and aircrew mission effectiveness without further burdening pilot task workload. To ensure that the end-users' explicit map needs are taken into consideration, investigators elicited one-on-one aircrew evaluations of a wide variety of map data types (both topographic and tactical) and map display parameters, including feature size, orientation, color, symbology, etc., to help define an optimum map design for cockpit displays.

1.2 Background

In support of this objective, the Tactical Aircraft Moving Map Capability (TAMMAC) Integrated Program Team (IPT) at NAVAIR (PMA 209) funded investigators from the Naval Research Laboratory, Stennis Space Center, MS (NRLSSC), to identify and demonstrate which digital map products would be best suited to support end-user requirements for advanced cockpit map displays. The results of this work may benefit mission planning displays as well, although mission planners are not explicitly targeted in this study.

NRLSSC designed 16 task-structured demonstrations of various digital moving map scenarios, using standard National Imagery and Mapping Agency (NIMA) products (including both existing and prototype databases), and presented the displays to experienced aircrew from diverse aircraft platforms. We asked the pilots to evaluate each moving map display in terms of its potential usefulness for their specific applications.

We attempted to simulate realistic mission scenarios, but due to time and funding constraints, we were unable to incorporate the map displays into a flight simulator. Instead, we developed and presented the demonstrations on a Silicon Graphics, Inc. (SGI) workstation. We conducted the demonstrations and aircrew surveys at the Naval Air Warfare Center, Aircraft Division, Patuxent River, MD (NAWC-ADP), in conjunction with their Human Factors group.

1.3 Order of Report

This report documents the moving map demonstrations that were presented to pilots and aircrew at Patuxent River in August 1995, and presents the results of the coincident aircrew survey.

Following this *Introduction* section, an *Approach and Methods* section describes the in-depth questionnaire, interview sessions, and an overview of each demonstration, including hardware, software, and map data sources. The *Results and Recommendations* section of the report discusses each demonstration in detail, including a short description, summary of pertinent NAVAIR program requirements, survey results, and specific recommendations. The report closes with a *Summary*, *References*, and *Appendices*, which provide additional information on specific aircraft map requirements and the pilot surveys.

2.0 APPROACH AND METHODS

2.1 Questionnaire

The aircrew questionnaire consisted of a pilot introduction page, followed by one survey for each of the 16 demonstrations. All responses were entered into a database (Microsoft Access 2.00) for compilation and data analysis. The entire questionnaire is provided in App. A.

The pilot introduction section included information such as military service, primary and secondary aircraft, flight hours, night flight experience, combat experience, and experience with existing cockpit digital moving maps. This information was used to categorize the results and to consider whether a particular type of map data or display would be more useful for one type of aircraft, or whether a pilot's responses might be related to his or her flight experience or familiarity with digital moving maps.

Each map display survey started with a brief description of the demo, followed by a series of questions. The surveys were designed to be as quantitative as possible to facilitate data entry and analysis. Most questions required answers in one of the following forms:

- 5-point ranking of map data or display items (Table 1);
- Rating of items as either satisfactory or unsatisfactory;
- Multiple choice (e.g., "Which option(s) would you prefer: A, B, and/or C ?");
- Questions requiring short, one- to two-sentence answers.

2.2 Interview Sessions

NRLSSC interviewers conducted the demonstration for each pilot separately to encourage individual responses. Each pilot viewed a 6-min introductory video, followed by the demonstrations and questionnaire, then a brief wrap-up. The entire session typically lasted $1^1/_2$ h per pilot.

Table 1 — Demo Rating Scale

RATING	DESCRIPTION
1	Of No Use
2	Not Very Useful
3	Of Use
4	Of Considerable Use
5	Extremely Useful

The introductory video gave each pilot an overview of this project, the chief objectives, and some examples of the demonstrations they would be viewing and the questions they would be asked. The participants also filled out the pilot introduction sheet at this time.

Each of the 16 demonstrations was between 1–5 min long. For each demonstration, the interviewer asked the pilot to read the brief description and all questions on that demo's survey sheet before viewing the demo. The pilot could view the demo more than once, if desired. Each pilot could take as much time as necessary to answer all the questions about one demo before viewing the next. Each session was tape-recorded (with the participant's knowledge) to capture any comments that the pilot may not have written on the questionnaire.

Finally, each pilot was given about 10 min to wrap-up and make any additional comments about the demos or digital moving map displays in general. In an attempt to focus the pilot's final comments, the interviewer asked "If you were to go into combat tomorrow, is there one item from these demonstrations that you would want to take with you?" It was anticipated that their responses might shed some light on bottom-line priorities.

2.3 Demonstrations

The demonstrations were developed as computer-generated movie loops using ArcInfo Geographic Information System software and SGI Moviemaker software on SGI Crimson and Indigo workstations. Realistic ground speeds, aircraft turn rates, display refresh rates, and other parameters were simulated via Moviemaker by carefully controlling the window of map data displayed in each frame (including exact geographic area, image orientation, zoom factor, etc.) and the number of frames displayed per second. ArcInfo handled map projection and scale compatibility (between overlaid data sets). The simulated map display window was the same size as the current F/A-18 and AV-8B digital map displays, 4.5″ × 4.5″ (11.4 cm × 11.4 cm).

Each of the 16 demonstrations addressed one or more specific map data or display issues of particular interest to the TAMMAC team at NAVAIR. NAWC-ADP and NRLSSC developed a matrix of 46 map issues from the TAMMAC Requirements Database, which NAWC-ADP compiled from the sources listed in Table 2. Of the 46 original map issues, 24 were considered to be within the scope of this project and were evaluated during this study. This subset of 24 map issues is presented in App. B.

Based on the TAMMAC requirements, six principal map data types were selected for evaluation: scanned chart data, satellite imagery, terrain elevation data, data frames (such as reconnaissance photographs), vector map data, and mission planning symbols. Table 3 provides descriptions and source information for each of these data types.

Table 2 — Sources for TAMMAC Map Data Requirements by Aircraft Platform

AIRCRAFT	MAP DATA REQUIREMENTS SOURCES
AV-8B	PS 75-870134 Rev. A (Procurement Spec for Digital Map Set), 29 Oct 85
F/A-18 C/D	PS 75-870134 Rev. A (Procurement Spec for Digital Map Set), 29 Oct 85
F/A-18 E/F	PS 74-870300 (Procurement Spec for Multi-Purpose Color Display), 27 Jan 93
UH-1N	System Spec for UH-1N Multi-Function Display, NAWCADWAR, 14 Apr 94
V-22	V-22 Draft DMS Spec #901-947-855, 14 Mar 94; Digital Map System CIDS, Boeing Memo 8-7161-DM-276, 5 Apr 94; Supplier Statement of Work for DMS, Boeing Report #D901-99549-1, 1994; V-22 DMS, Vol. II - Eng. Doc #HP94-0501, Elbit, Fort Worth, TX, 17 Jun 94

Table 3 — Data Selected for Cockpit Moving Map Demonstrations

DATA TYPE	DATABASE NAME AND DESCRIPTION	SOURCE(S)
Scanned Chart Data	ARC Digitized Raster Graphics (ADRG), subsampled to 169 pixels/inch to emulate Compressed ADRG (CADRG), including the following scanned aeronautical charts: Acronym — Scale* — Range† — Full name GNC — 1:5M — 160 nmi — Global Navigation Charts JNC — 1:2M — 80 nmi — Jet Navigation Charts ONC — 1:1M — 40 nmi — Operational Navigation Charts TPC — 1:500k — 20 nmi — Tactical Pilotage Charts JOG — 1:250k — 10 nmi — Joint Operational Graphics TLM-100 — 1:100k — 4 nmi — Topographic Line Map-100 TLM-50 — 1:50k — 2 nmi — Topographic Line Map-50 *For scales: M = million, k = thousand. †Range based on current cockpit moving map displays (McDonnell Douglas Model #ASQ-196): top to bottom of screen.	NIMA
Satellite Imagery	Controlled Image Base (CIB): 10 m/pixel panchromatic Satellite Pour l'Observation de la Terre (SPOT) imagery enhanced via contrast-stretch algorithm (in ArcInfo). Equivalent scale: 1:50k (2 nmi range).	NIMA
Vector Map Data	Digital Chart of the World (DCW): vectorized version of the 1:1M scale ONC series (40 nmi range, pre-zoom).	NIMA
Terrain Data	Digital Terrain Elevation Data (DTED) Level 1: gridded elevation database (one grid point every 3 arc-seconds of latitude). Equivalent scale: 1:250k (10 nmi range).	NIMA
Data Frames	Any static image, such as a reconnaissance photograph, emergency checklist, etc. Samples used in this study were reconnaissance photos at varying scales.	NIMA
Mission Planning Symbols	Bitmapped (raster) versions of cartographic symbols representing threats, targets, routes, waypoints, etc. Included symbols from AV-8B and V-22 mission planning sets.	TAMPS, MOMS

TAMPS = Tactical Aircraft Mission Planning System

MOMS = Map, Operator, and Maintenance Stations

China Lake, CA, was chosen as the geographic area of interest for the simulated moving map displays primarily because all the map databases to be demonstrated included coverage of that area. The CIB database, in particular, had very limited geographic coverage, but it did include China Lake.

Throughout the demonstrations, ground speed was simulated at several different velocities, ranging from 0 to 480 kt, to consider how the moving map might behave in various aircraft (e.g., hovering or slower moving helicopters, as well as faster tactical aircraft). Turns were simulated at 7 degrees per second (deg/s) unless otherwise stated.

The 16 demonstrations were grouped into six general categories, based on the map data and display issues to be addressed: timing, map positioning, zooming, terrain elevation data, overlay data, and future moving map displays. Table 4 lists each demo by category.

3.0 PILOT PROFILE

This section presents the results of the pilot information surveys, including aircraft platforms represented, military services represented, and pilot experience (e.g., number of flight hours, combat experience, and digital moving map experience).

3.1 Aircraft and Services Represented

NRLSSC and NAWC-ADP interviewed a total of 30 pilots, representing 14 different aircraft platforms (Table 5) from the Navy, Marine Corps, and Air Force (Fig. 1). Although the original intent was to survey only tactical pilots, several nontactical groups were also represented (e.g., helicopter pilots, antisubmarine warfare (ASW) pilots, and aircrew). In hopes that this diversity would shed insight on the potential differences in map data requirements as a function of aircraft type and mission, many of the survey results were categorized by general aircraft category (*Tactical, Helicopter,* and *ASW,* as listed in Table 5).

Participants were asked to list their primary and secondary aircraft; however, this report bases its results and recommendations on primary aircraft only. A larger sample size would be required before responses could be successfully linked to more than one aircraft per participant with any consistent results.

Table 4 — List of All Demonstrations by Category

TIMING	TERRAIN ELEVATION DATA
(1) Time to Switch Map Modes (2) Time to Switch Scales (3) Time to Reposition to Lat/Lon (4) Data Update/Refresh Rates	(10) Contours vs. Shading (11) Contour Intervals (12) Sun-Angle Shading (2-D and 3-D)
MAP POSITIONING	**OVERLAY DATA**
(5) Centered vs. Decentered in North-Up and Track-Up	(13) Height Above Terrain (HAT) Over Chart or Imagery (14) Clear Line of Sight (CLOS) Over Imagery (15) Threat Intervisibility
ZOOMING	**VECTOR MAPS**
(6) Zoom vs. Chart Series Switches (7) Number of Steps to Zoom (8) Zoom-Out Capability (9) Range vs. Legibility Issues	(16) Vector Moving Map Display

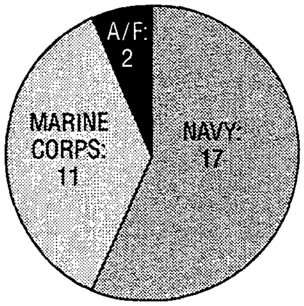

Fig. 1 — Military services represented in survey

Table 5 — Aircraft Types Represented in Survey

TACTICAL: 15		HELICOPTER: 9		ASW: 6	
A/C	#PILOTS	A/C	#PILOTS	A/C	#PILOTS
F/A-18	6	AH-1W	2	P-3	3
A-6	2	CH-46	2	S-3	2
AV-8B	2	CH-53E	2	V-22	1
EA-7	2	UH-1N	2		
F-14	2	H-60	1		
A-10*	1				

The A-10 pilot was interviewed during a preliminary survey. He did not respond to all questions, resulting in a total of 14 tactical pilots (29 total pilots) for some demos.

3.2 Pilot Experience

The pilot introduction survey gauged pilot experience in several ways: number of flight hours, percentage of hours flown at night, combat flight experience (*none; limited*; or *experienced*), flight instructor experience (*yes* or *no*), and digital moving map experience (*no experience*; *familiar with concept*; *limited experience*; *occasional use*; or *current and experienced user*).

3.2.1 Flight Hours

The majority of surveyed pilots had logged between 1000–3000 total flight hours, including between 1000–2000 h in their primary aircraft (Fig. 2). The least experienced participants (in terms of total flight hours) were two EA-7 aircrew members, who each had 1100 total flight hours (including 600 h each in the EA-7). The most experienced participant was a P-3 pilot with 6000 total hours (including 1000 in the P-3). The average number of total flight hours cited was 2400; the average number of flight hours in pilots' primary aircraft was 1490.

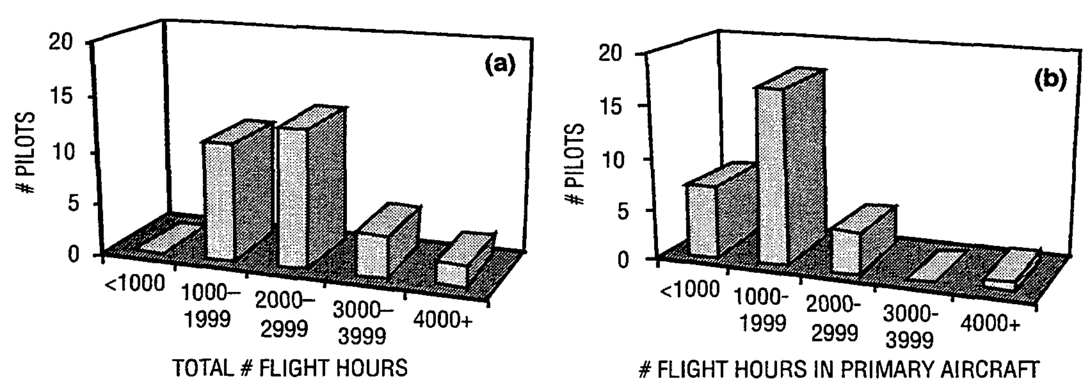

Fig. 2 — Flight hours for surveyed pilots: (a) total number of flight hours and (b) number of flight hours in primary aircraft

3.2.2 Night Flying Experience

The survey recorded nighttime flight hours as well. The percentage of flight hours that were at night ranged from 5–50% (or 55–3000 h) for this population, with an average of just over 30% (860 h). The number of night flight hours was determined by applying each pilot's night flight percentage to his or her total flight hours.

3.2.3 Combat Experience

The survey asked pilots to describe their own combat flight experience by selecting one of the following options: (1) No combat experience; (2) limited combat experience; or (3) experienced combat pilot. Table 6 shows that half of the surveyed pilots had no combat experience and one-third had limited experience. Only three respondents rated themselves experienced combat pilots.

3.2.4 Flight Instructors

The survey recorded whether each pilot was a certified flight instructor as another indication of overall flight experience. Of the 30 pilots interviewed, 17 were instructors (57%), suggesting a relatively mature and experienced pilot population.

3.2.5 Digital Moving Map Experience

Finally, the survey asked participants to assess their experience with cockpit moving maps by selecting one of the following options: (1) No experience; (2) familiar with concept; (3) limited experience (e.g., in a simulator); (4) occasional use in cockpit; or (5) current use and very experienced. As shown in Table 7, 77% of the pilots in this sample had some experience with cockpit moving maps, 54% had flown (frequently or occasionally) with a cockpit moving map, and 23% had limited experience. Another 20% of the pilots had no first-hand experience with moving maps, but were familiar with the concept. Only one pilot claimed to have no experience with this technology. These responses suggest a fairly sophisticated pilot population that is familiar with digital cockpit moving maps.

4.0 RESULTS AND RECOMMENDATIONS

This section presents the results of the demonstration surveys, including a brief description of each demonstration and any known preliminary aircraft program specifications related to the demo

Table 6 — Combat Experience of Participants

DESCRIPTION	# PILOTS
No Combat Experience	15 (50%)
Limited Combat Experience	10 (33%)
Experienced Combat Pilot	3 (10%)
No Answer	2 (7%)

Table 7 — Digital Moving Map Experience of Participants

DESCRIPTION	# PILOTS
Current Use and Very Experienced	5 (17%)
Occasional Use in Cockpit	11 (37%)
Limited Experience (e.g., in a simulator)	7 (23%)
Familiar With Concept	6 (20%)
No Digital Moving Map Experience	1 (3%)

(also listed in App. B). The discussion of demonstration surveys is organized by demo category (Table 4) and provides category-specific survey results and recommendations following the demo descriptions.

4.1 Timing Requirements

4.1.1 Description

The first three demos in this category demonstrated varying times to switch the map display from one view to another. As a switch started in each demo, a programmed sound bite in the computer said "switching." To illustrate the amount of time taken to perform the switch, the display turned black the instant a pilot made the "request," and it returned to its original color the instant the display was changed. The request in each case was simulated; none of the demos was interactive. Participants were not told how much time each switch took; instead, they were told to evaluate each switch time as either satisfactory or unsatisfactory.

The last demo in this category evaluated data update rates, or the speed at which the map computer displays each new frame of information. The display update rate determines how well the moving map display can "keep up" with the speed of the aircraft. In all four timing demos, chart data refers to subsampled ADRG JOG data (see Table 3) unless otherwise indicated.

Demo #1: Time to Switch Map Modes: Demonstrated three different delay times to switch between map modes (or data types): 1 s (switch time *A*), 2 s (*B*), and 3 s (*C*). Preliminary specifications for the V-22 program called for a switch time of 1 s or less for this function; the preliminary UH-1N specification was 3 s or less (App. B, items 8, 11, and 39). For each switch time, the map display changed from a JOG chart to satellite imagery to terrain data to a data frame (Fig. 3a–d). Each map mode was displayed for 5 s before switching to the next mode.

The demo displayed the first three modes as north-up moving maps; the data frame was a static image. The JOG chart and terrain data were displayed at a scale of 1:250k (which equates to 10 nmi from screen top to bottom), and the satellite imagery was displayed at a scale of 1:50k (2 nmi range). The data frame was a reconnaissance photograph (approximately 0.5 nmi range).

Demo #2: Time to Switch Scales: Demonstrated three different delay times to switch between chart scales: 0.5 s (switch time *A*), 1 s (*B*), and 2 s (*C*). Preliminary UH-1N specifications called for a switch time of 1 s or less for this function (App. B, item 6). For each switch time, the map display changed from JOG (10 nmi range) to TPC (20 nmi range) and back to JOG (Fig. 4). Each chart series/scale was displayed for 5 s before switching to the next series. All displays were north-up moving maps.

Demo #3: Time to Switch from Moving Map to Command Lat/Lon Reposition: Demonstrated three different times to reposition a moving map to a specified point: 0.5 s (switch time *A*), 1 s (*B*), and 2 s (*C*). The UH-1N program specified a switch time of 1 s or less for this function (App. B, item 32). For each switch time, the display switched from a moving chart centered on aircraft position to a static chart centered on a "pilot-specified" latitude and longitude point (outside the original display range), and back to the aircraft-centered moving chart (Fig. 5). Each view was shown for 5 s before switching to the next view.

Demo #4: Data Update/Refresh Rates: Compared two different data update rates (15 and 20 Hz) for varying aircraft speeds. The V-22 program specified a data update rate of 15 Hz;

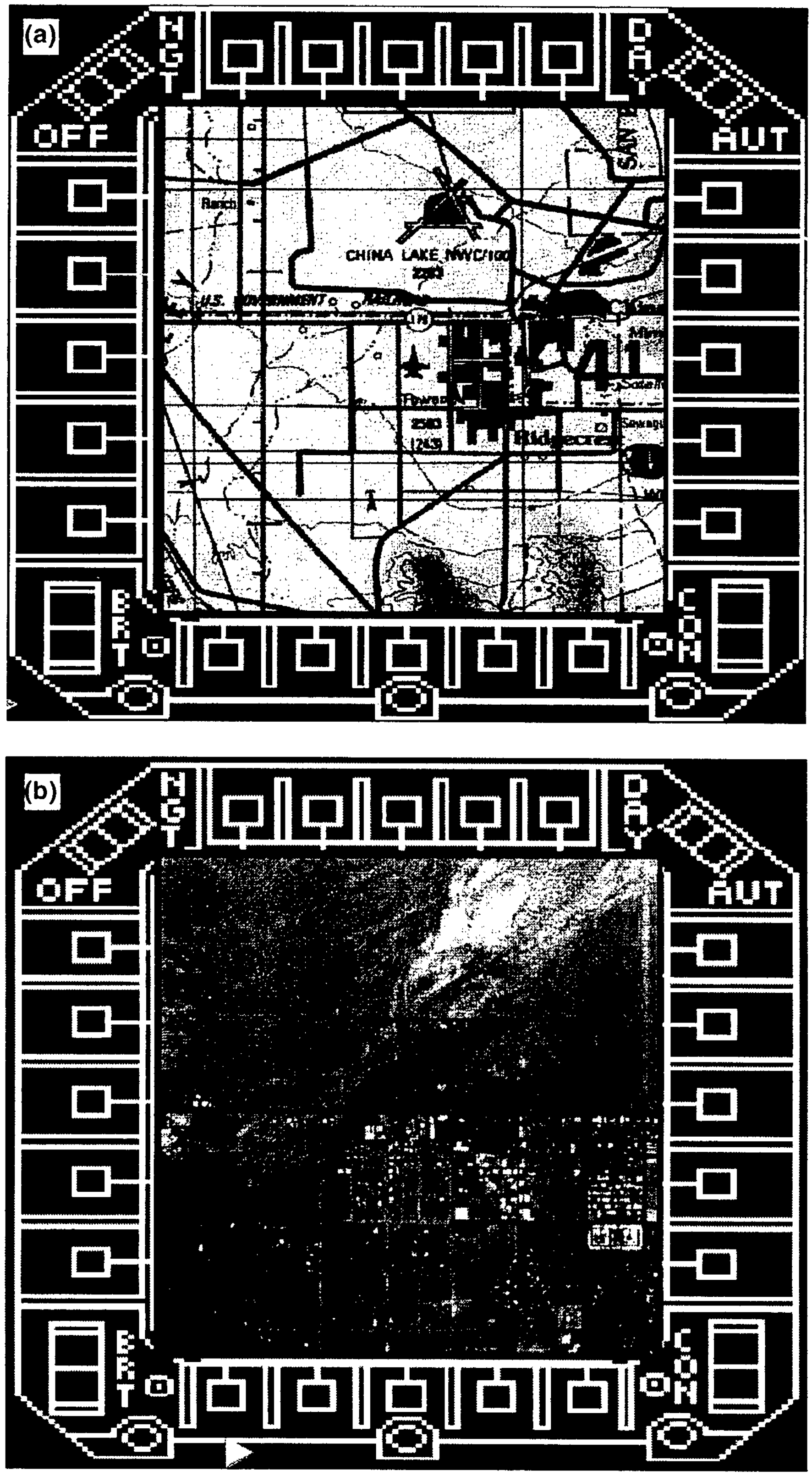

Fig. 3 — Demo 1 of four map modes, centered, north-up display: (a) CADRG data, JOG chart, 10 nmi range and (b) satellite imagery, CIB/SPOT, 2 nmi range

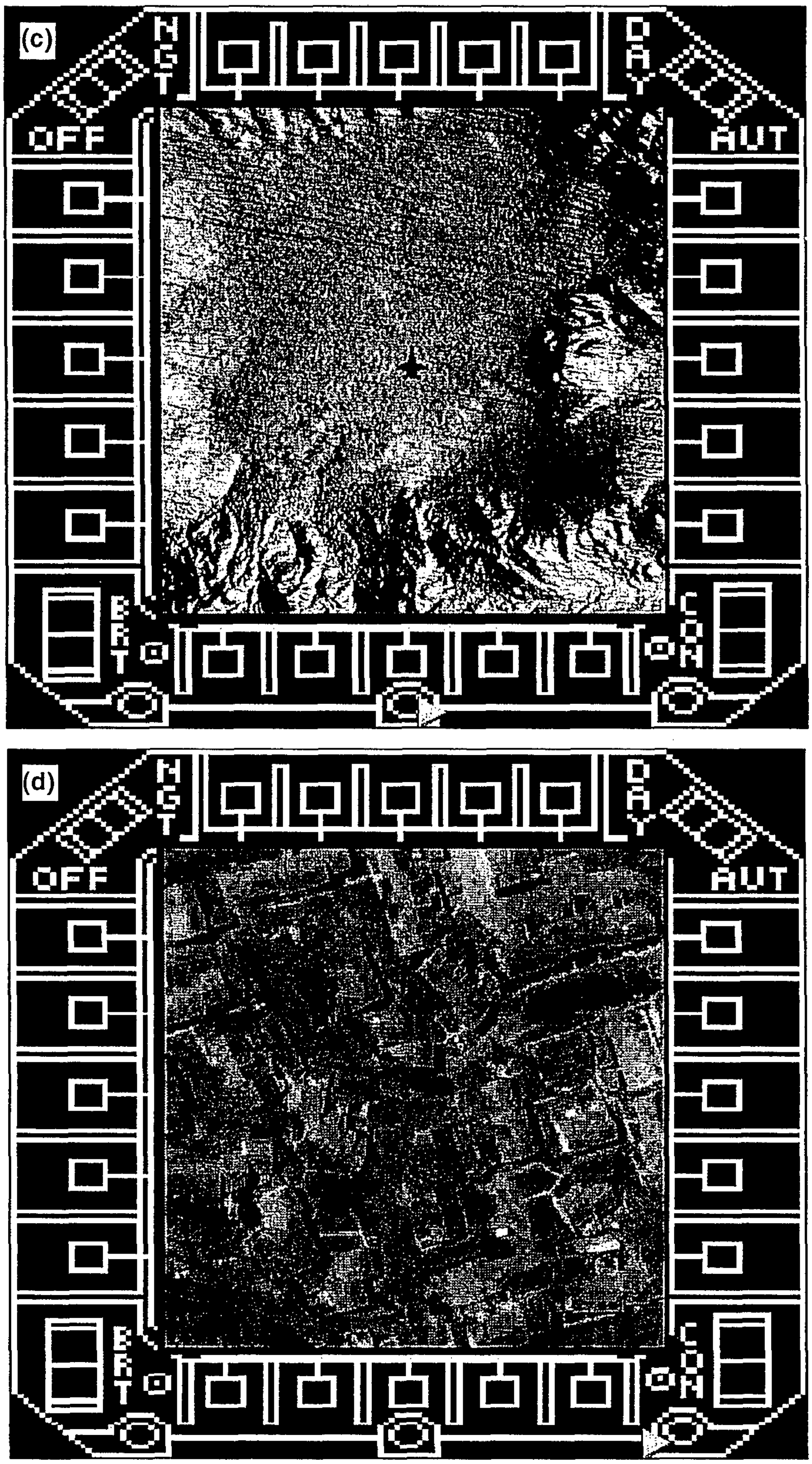

Fig. 3 — (cont.) (c) terrain elevation data, DTED, 10 nmi range and (d) dataframe, reconnaissance photo, 0.5 nmi range

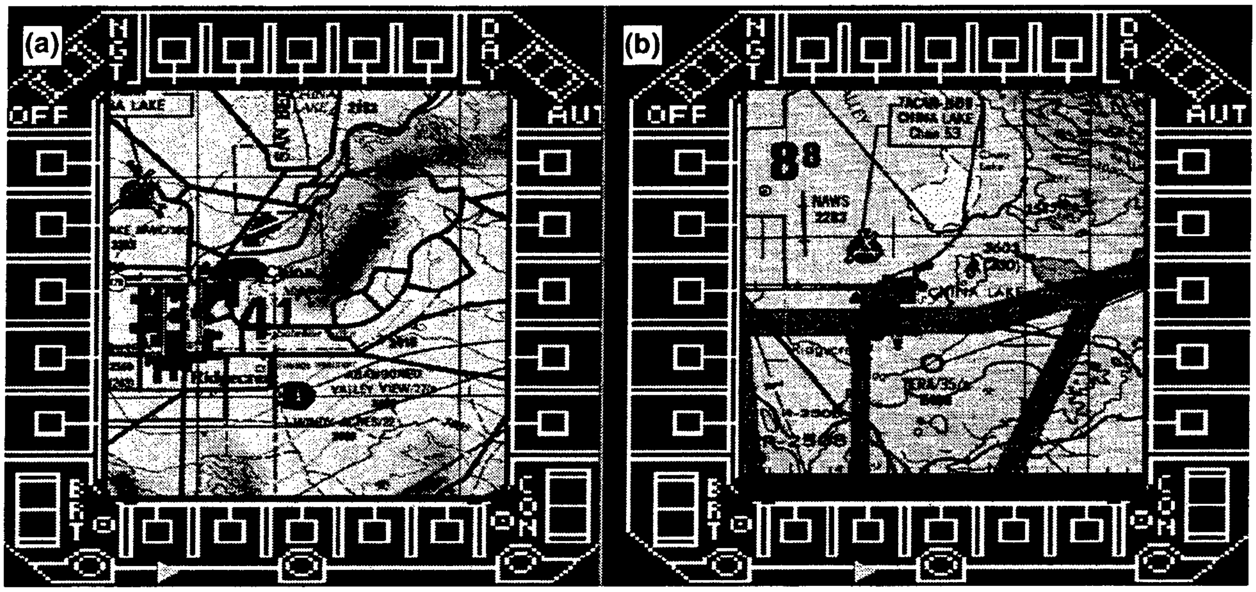

Fig. 4 — Demo 2: switching between two chart scales, centered, north-up displays: (a) JOG (1:250k scale) and (b) TPC (1:500k scale)

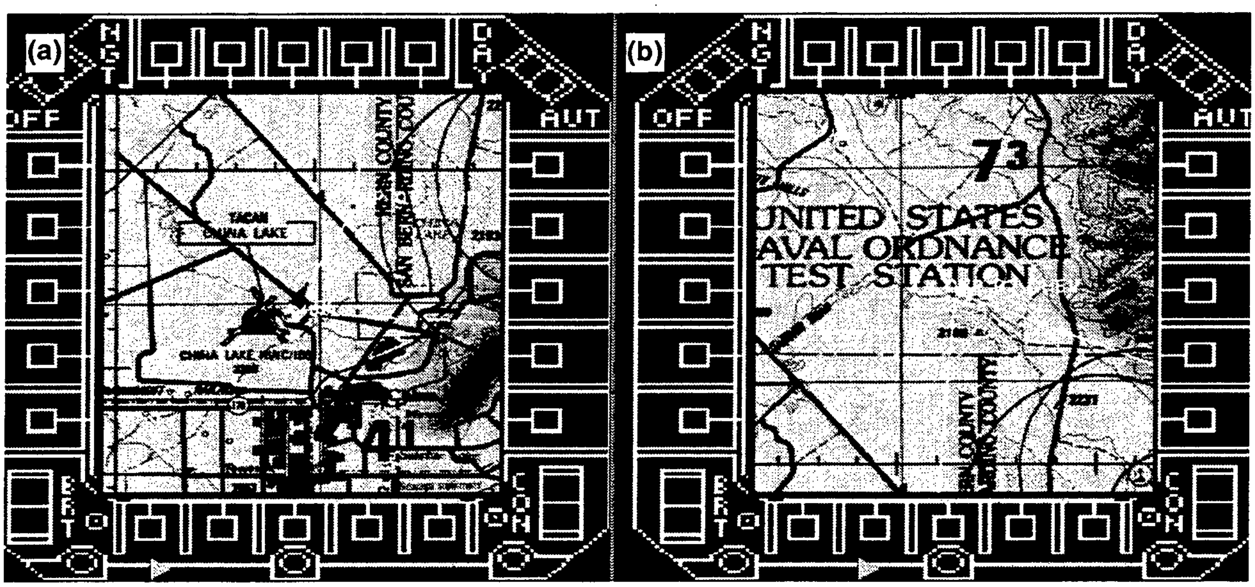

Fig. 5 — Demo 3: switching from moving map to repositioned chart, centered, north-up displays (both JOG 1:250k scale): (a) moving map and (b) repositioned chart

preliminary TAMMAC specifications called for 20 Hz (App. B, item 1). A rate of 15 Hz was simulated by displaying 15 frames/s (a new frame was displayed every 66 ms), and 20 Hz was simulated by displaying 20 frames/s (a new frame was displayed every 50 ms). For each update rate, ground speed was simulated at 0, 90, 200, and 300 kt with the aircraft in a 7 deg/s turn.

4.1.2 Results

Tables 8 and 9 present the results of the timing studies. In the first demo (which switched among four different "map modes" or data types), switch times of 1 s, 2 s, and 3 s were presented.

Table 8 — Acceptance Values for Switch Times (Demos 1, 2, and 3)

ACCEPTANCE OF DELAY (% of Surveyed Pilots that Considered the Delay Acceptable)				
DEMO #/DESCRIPTION	0.5 s	1 s	2 s	3 s
Switch/Map Modes	–	**100%**	**40%**	**3%**
Tactical	–	15 / 15	5 / 15	0 / 15
Helicopter	–	9 / 9	5 / 9	1 / 9
ASW	–	6 / 6	2 / 6	0 / 6
Switch Chart Scales	**100%**	**77%**	**13%**	–
Tactical	15 / 15	9 / 15	3 / 15	–
Helicopter	9 / 9	8 / 9	1 / 9	–
ASW	6 / 6	6 / 6	0 / 6	–
Command Reposition	**100%**	**83%**	**20%**	–
Tactical	15 / 15	11 / 15	4 / 15	–
Helicopter	9 / 9	8 / 9	1 / 9	–
ASW	6 / 6	6 / 6	1 / 6	–

Table 9 — Acceptance Values for Data Update Rates (Demo 4)

ACCEPTANCE OF DATA UPDATE RATES (% of Surveyed Pilots that Considered the Rate Acceptable)			
DEMO #4 DESCRIPTIONS	15 Hz	20 Hz	NEITHER
Data Update Rates @ 0 kt	**97%**	**83%**	**0%**
Tactical	13 / 14	11 / 14	0 / 14
Helicopter	9 / 9	7 / 9	0 / 9
ASW	6 / 6	6 / 6	0 / 6
Data Update Rates @ 90 kt	**97%**	**76%**	**0%**
Tactical	13 / 14	10 / 14	0 / 14
Helicopter	9 / 9	6 / 9	0 / 9
ASW	6 / 6	6 / 6	0 / 6
Data Update Rates @ 200 kt	**97%**	**69%**	**0%**
Tactical	13 / 14	10 / 14	0 / 14
Helicopter	9 / 9	4 / 9	0 / 9
ASW	6 / 6	6 / 6	0 / 6
Data Update Rates @ 300 kt	**93%**	**72%**	**3%**
Tactical	13 / 14	10 / 14	0 / 14
Helicopter	8 / 9	5 / 9	1 / 9
ASW	6 / 6	6 / 6	0 / 6

All surveyed pilots accepted the 1-s delay as satisfactory; less than half of the pilots accepted a 2-s delay, and only one pilot accepted a 3-s delay.

In both the second demo (switching between chart scales) and the third demo (switching from a moving map to a command-repositioned chart), switch times of 0.5 s, 1 s, and 2 s were presented. Again, all surveyed pilots accepted the fastest time switch, which was 0.5 s in these cases. Approximately 80% of the pilots accepted a 1-s delay for scale switches and for command repositions, as opposed to the 100% acceptance of a 1-s delay to switch map modes. Only 13% and 20% of the pilots accepted a 2-s delay for scale switches and command repositions, respectively, as opposed to a 40% acceptance for a 2-s delay to switch map modes.

There are at least two possible explanations for the disparity of acceptance between the first demo and the second/third demos, with regard to the 1- and 2-s switches. First, each demo presented these time delays to the pilots in order of fastest to slowest. Although the pilots were not informed of this pattern, they may have learned to anticipate progressively slower switches and chose the fastest (the first option in each demo) as the most acceptable. Similarly, the second option in each demo tended to be less acceptable than the first, since it was obviously slower, and the last option tended to be the least acceptable, since it was perceived to be the worst case. This bias could be minimized in future surveys by randomizing the presentation of switch times.

A second possible explanation for the disparity of acceptance between the demos is that the participants could tolerate a longer delay in switching between different map modes as compared to switching between chart scales or command repositions. This explanation is supported by the significant difference in acceptance of a 1-s delay between tactical pilots and all other pilots. All pilots considered a 1-s delay to be acceptable when switching map modes, and all but one of the nontactical pilots rated this delay acceptable for switching scales and switching to a command repositioned area. However, only two-thirds of the tactical pilots considered a 1-s delay acceptable for switching scales and repositioning.

More tactical and helicopter pilots rated the 15-Hz data update rate acceptable than the 20-Hz display at the four demonstrated ground speeds (a chi-square test showed their preference for 15 Hz to be significant at $\alpha = 0.01$). ASW pilots found no difference between the two data update rates. These results were unexpected, since it was theorized that the faster display (20 Hz) would be better. Once again, the pilots may have been conditioned to expect that the first segments of a demo were the best (fastest) and that later segments were less acceptable. Nevertheless, even pilots who viewed both options (15 Hz and 20 Hz) several times could not identify a significant difference between the speeds, and more pilots rated 15 Hz as acceptable than 20 Hz.

Pilots' written (and taped) comments provide additional information about data update rate requirements. Pilots stated that "Time A [15 Hz] was smoother," and "Time B [20 Hz] jittered more" or was "rachety." At least one pilot (V-22) stated that the preferred update rate (15 Hz) must be maintained while displaying *all* mission planning/waypoint symbols on the map. He stated that this is a problem with current map displays; the map has trouble "keeping up" with the aircraft position after all the necessary symbols have been overlaid. Two other pilots (UH-1N and AH-1W) cautioned that neither of the simulated data update rates (15 Hz nor 20 Hz) may be acceptable during a typical helicopter turn (20–40 deg/s as opposed to the demonstration's turn rate of 7 deg/s), and that update rates should be demonstrated at faster turns before they could accurately evaluate them.

4.1.3 Summary and Recommendations

Times to switch: "Faster is better" accurately sums up the pilots' preferences with regard to all three time-to-switch functions (switching map modes, switching chart scales, and command lat/lon repositions). All participants rated 0.5 s satisfactory for switching chart scales and for command repositions, and although 0.5 s was not an option for the map mode switches, the pilots would undoubtedly find 0.5 s satisfactory for that function as well. All tactical pilots rated 1 s as satisfactory for switching map modes, and most tactical pilots rated 1 s as satisfactory for scale switches and command repositions. All but one nontactical pilot rated 1 s as satisfactory for all three switch functions. Most pilots (tactical and nontactical) rated 2 s as *unsatisfactory* for all three functions. All but one pilot rated 3 s as *unsatisfactory* for map mode switches, and although 3 s was not an option for scale switches or command repositions, these pilots would certainly find 3 s unsatisfactory for those functions as well.

Based on these results, the authors most highly recommend a 0.5-s time to switch for all three functions. If 0.5 is cost-prohibitive, however, a 1-s time to switch would be acceptable. This study found that 2 s or longer is unacceptable for any of the demonstrated functions. Note that these results reflect what pilots want to see on a fully functional cockpit moving map display (i.e., a moving map overlaid with all necessary mission planning symbols). It is important to consider that other instruments utilizing the cockpit computer will contribute to latency, so it may be necessary to specify a faster switch time (e.g., 0.5 s) to ensure satisfactory performance (e.g., 1 s) in a fully functional cockpit system.

Data Update Rates: It is interesting that the "faster is better" rule does *not* apply to data update rates. Pilots tended to prefer the demonstrated 15-Hz displays over equivalent 20-Hz displays, although this preference was apparently related to aircraft type (see Table 9). Tactical and helicopter pilots showed a moderate preference for the 15-Hz display, but ASW pilots showed absolutely no preference for one rate or the other. These results might be due to experiment error (e.g., inaccurately simulating data update rates that were slower than the computer's default display rate), they might have been due to pilot conditioning (expecting faster segments of the demonstration first), or they might suggest that faster data update rates are not necessarily better for cockpit moving maps. If this experiment were repeated, investigators should present randomized data update rates to ascertain whether the lower rate is really more acceptable.

Based on the results, a 15-Hz data update rate seems to be acceptable for the TAMMAC system. However, moving map system developers must ensure that this rate is maintained with a full load on the computer (i.e., when all other aircraft systems that utilize the map computer are running). Also, the 15-Hz display rate must be maintained whenever all necessary overlays have been added to the base map (e.g., threat rings, routes, targets, HAT, etc.) Pilots in this study commented that this is not the case with existing cockpit map systems—their map has had difficulty keeping up with the aircraft position after all the necessary symbols were overlaid, which was disorienting and unacceptable.

4.2 Map Positioning Requirements

4.2.1 Description

Demo #5: Centered vs. Decentered Modes in North-Up and Track-Up: Demonstrated four different aircraft cursor positions and their effect on the moving map coverage: centered (aircraft cursor in the center of the display), ¼-up (aircraft cursor 25% up from the bottom of the screen), 1/7-up (14% up from the bottom), and bottom-of-screen. Each of these positions was demonstrated first in north-up mode (Fig. 6a–d) then track-up (Fig. 7a–d). For each variation, the computer played back a recorded sound bite that identified what was being displayed: "aircraft is centered;" "aircraft is one-quarter up;" etc.

All aircraft programs required a centered cursor option. For decentered options, preliminary TAMMAC and UH-1N requirements specified 1/4-up (listed as 75% in App. B, item 31, referencing the aircraft cursor to the top of the screen); V-22 required 1/7-up (listed as 86% in App. B); and the decentered position in current F/A-18 and AV-8B display systems is at the bottom of the screen (listed as 100% in App. B).

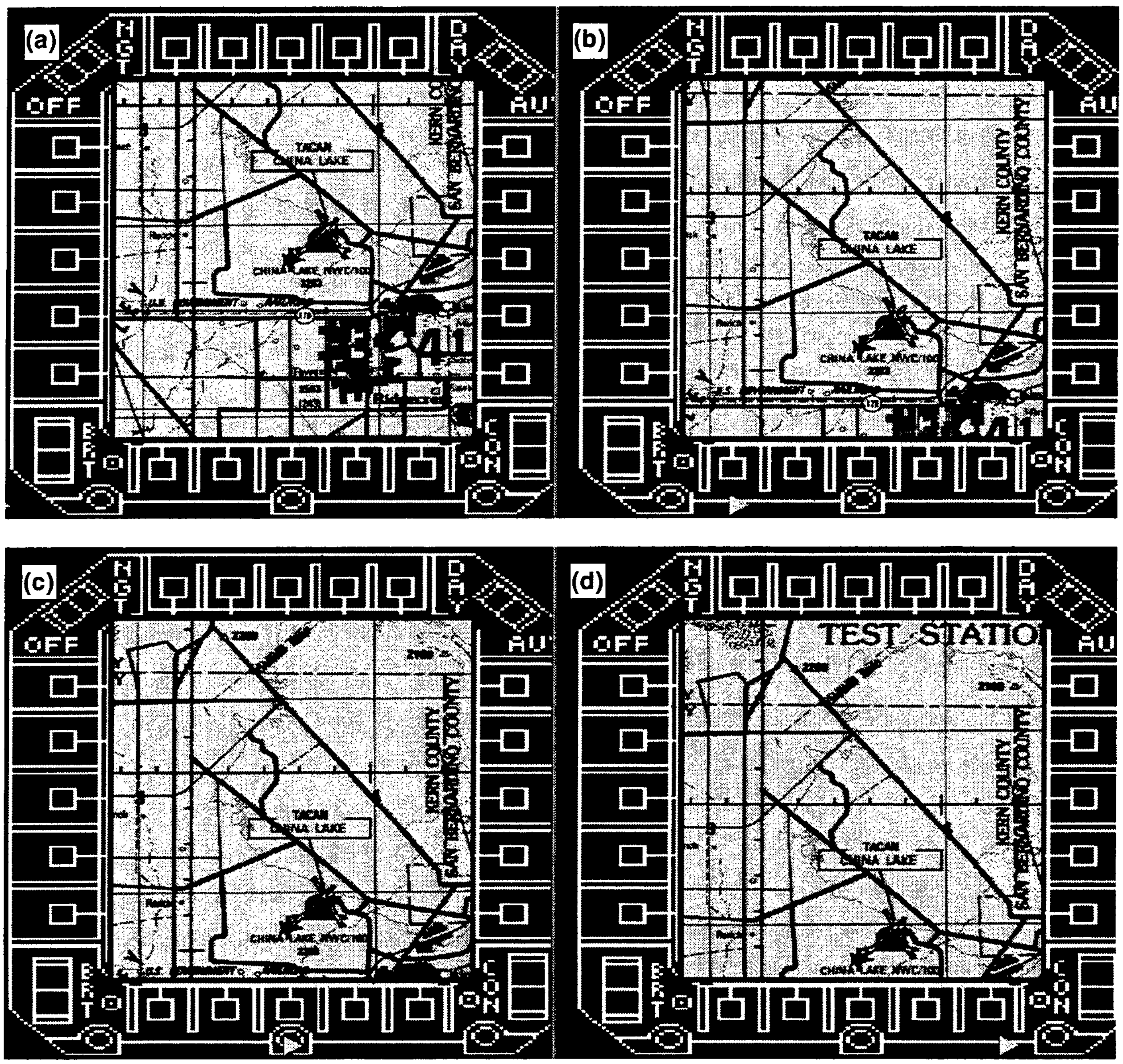

Fig. 6 — Demo 5: north-up moving map (JOG chart, 1:250k scale), (a) aircraft centered; (b) decentered 1/4-up; (c) decentered 1/7-up; and (d) decentered bottom-of-screen

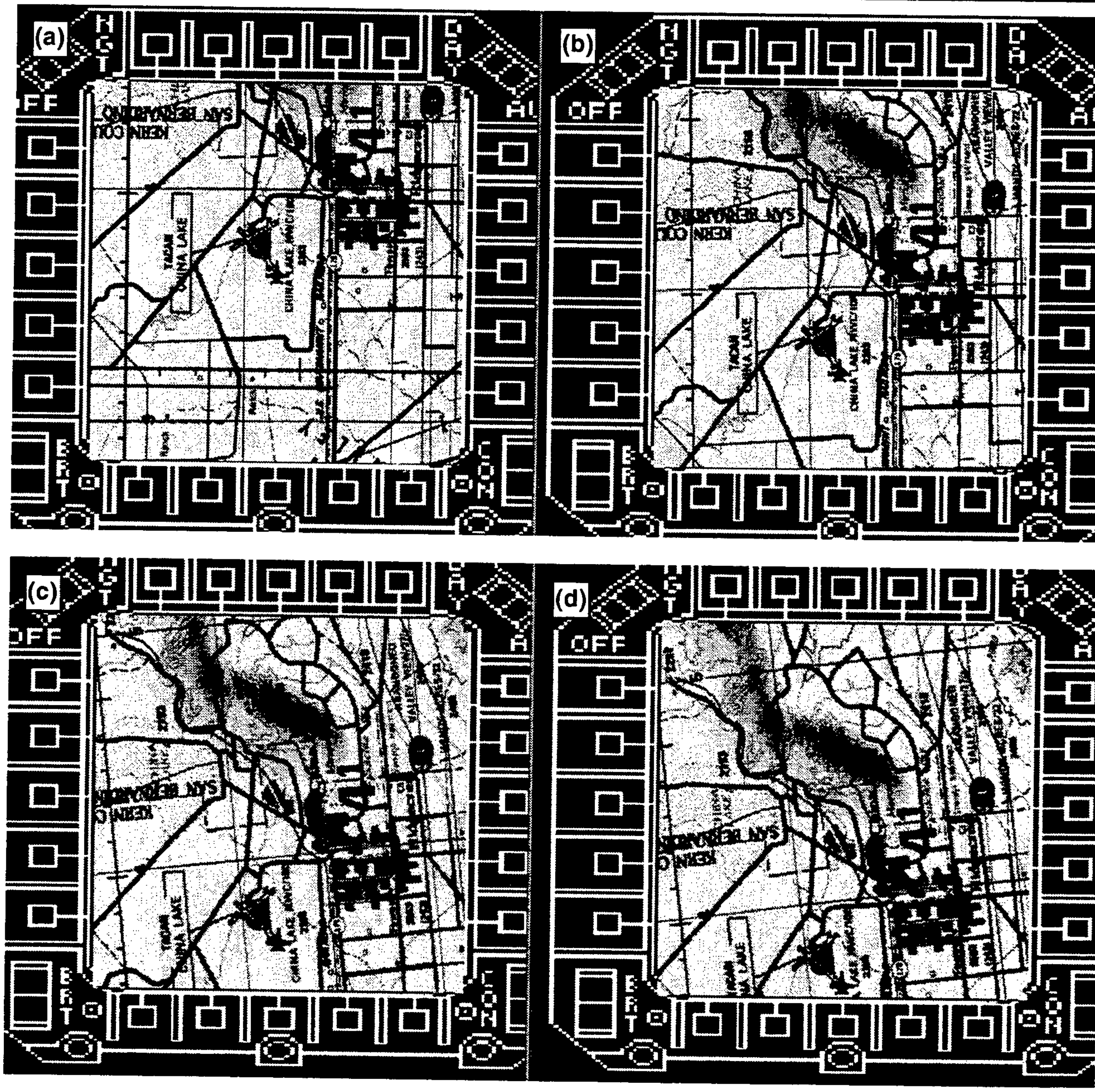

Fig. 7 — Demo 5: track-up moving map (JOG chart, 1:250k scale) with (a) aircraft centered; (b) decentered 1/4-up; (c) decentered 1/7-up; and (d) decentered bottom-of-screen

4.2.2 Results

Table 10 presents the results of the map positioning survey.

North-Up: As could be expected, all pilots preferred a centered display over any degree of decenter while the map was north-up. Some participants found a slightly decentered position (1/4-up) to be useful, but very few liked 1/7-up in a north-up mode, and no pilots liked a bottom-of-screen position for north-up, since any aircraft headings other than due-north would result in a significant loss of forward-looking map information.

Table 10 — Ratings of Map Positions (Demo 5): 1 = Of *No* Use; 2 = Not Very Useful; 3 = Of Use; 4 = Of Considerable Use; 5 = Extremely Useful

DEMO DESCRIPTION	AVERAGE RATING (of a possible 5)		DEMO DESCRIPTION	AVERAGE RATING (of a possible 5)	
	NORTH-UP	TRACK-UP		NORTH-UP	TRACK-UP
Centered	**4.0**	**4.5**	**1/7 Up**	**1.7**	**3.7**
Tactical	3.7	4.5	Tactical	1.5	3.6
Helicopter	4.3	4.4	Helicopter	2.0	4.1
ASW	4.2	4.5	ASW	1.7	3.2
1/4 Up	**2.2**	**4.5**	**Bottom**	**1.2**	**2.8**
Tactical	2.2	4.5	Tactical	1.1	2.7
Helicopter	2.9	4.7	Helicopter	1.4	2.8
ASW	1.8	4.2	ASW	1.2	3.2

Track-Up: The majority of pilots in all categories found both centered and 1/4-up positions to be *extremely useful* (most ratings were 4 or 5 on a 5-point scale) in track-up mode. Most pilots also found the 1/7-up position to be of some use. Fewer pilots liked the bottom-of-screen position, even in track-up, citing a loss of SA. Many pilots commented on the need for some map information behind the aircraft, which is lost in a bottom-of-screen position. Nearly all pilots stated a preference for track-up over north-up, and some helicopter pilots stated a need for a heading-up mode. The following is a representative sample of pilot and aircrew comments concerning their preferences with regard to north-up vs. track-up and centered vs. decentered map positions:

Tactical pilots:

- "Prefer track-up for most tactical applications."
- "Don't like bottom-of-screen (position): lose SA in one quadrant."
- "Track-up, 1/4-up (from the bottom of the screen) gives the best balance of information in front of and behind the aircraft."
- "North-up is disorienting in flight, but a good tool for preflight checks or waypoint insertion."

Helicopter pilots:

- "Track-up ... allows the pilot to keep essential information oriented ahead of the aircraft."
- "For helo, track-up isn't heading-up. In low-airspeed flight, it would be better to show heading up to minimize 'display flopping'."

ASW pilots:

- "Preferred track-up, 1/4 up ... If you could keep letters upright, this would be perfect!"
- "Track-up is definitely better. There is utility in having the aircraft at 1/4 or (at the) bottom if you need a bigger picture in front of you."

The questionnaire also asked pilots if they would want to have control over the degree of decenter for their aircraft cursor (e.g., to change it from 1/4-up to bottom-of-screen). Of the 30 pilots surveyed, only three wanted *no* control over the cursor position. Most wanted to be able to change the aircraft cursor position at any time (during mission planning or in the cockpit), as shown in Table 11. Participants' reasons for wanting this control centered on their need for improved SA and more flexibility to address the wide variety of pilot preferences and tactical situations.

Two helicopter pilots (UH-1N and AH-1W) wanted even more map positioning freedom than the demo presented. One asked for "complete freedom of position using a joystick or (toggle) switch," and the other called for decentered cursors to the "left and right for slewing information (threat rings, etc.) when the threat is known to be parallel to the course." One of the three pilots who did not want in-flight control over map positioning suggested customizing the default position to each aircraft platform via software.

4.2.3 Summary and Recommendations

Most pilots wanted both centered and decentered cursor positions on the digital moving map display, and they wanted both track-up and north-up modes. Helicopter pilots also requested a heading-up mode for more accurate map tracking without "display flopping." Nearly all participants wanted some control over the percentage of decenter (e.g., 75% decentered vs. 100% decentered); most wanted control both in mission planning and in the cockpit.

In track-up mode, pilots found both the centered position and the 1/4-up position to be *extremely useful* and the 1/7-up position was rated *of considerable use*. The bottom-of-screen was not as

Table 11 — Pilot Preferences for Control of Default Aircraft Cursor Position Relative to Map

OPTIONS FOR AIRCRAFT CURSOR POSITION	# PILOTS
Preset Default, Unalterable	**3**
Preset Default, Pilot-Changeable:	
Change in Mission Planning Only	0
Change in Cockpit Only	4
Change in Mission Planning or Cockpit	11
No Preference	0
Pilot-Selectable Default:	
Set in Mission Planning Only	0
Set in Cockpit Only	2
Set in Mission Planning or Cockpit	9
No Preference	0
No Preference	**0**
No Answer	**1**
TOTAL	**30**

popular, primarily due to a loss of SA behind the aircraft, but it was still rated *of use*. A few pilots said they would occasionally switch from a more centered position to a bottom-of-screen position, particularly at higher speeds, to keep as much map in front of the aircraft as possible. In north-up mode, all pilots favored the centered position (which they rated *of considerable use*), and they found all decentered positions to be *not very useful* or *of no use*.

Regardless of aircraft cursor position, most participating pilots stated that a track-up mode is significantly more useful to them than north-up for improved SA. These pilots' opinions support the findings of Aretz and Wickens (1992), who concluded that people interpret maps more easily in a track-up alignment, and that track-up may be the best alternative for electronic map displays. Aretz (1991) explains that whenever the north-up alignment does not match the direction of travel (i.e., the aircraft is flying in any direction other than due north), the pilot must perform a mental rotation to accurately interpret the map. Earlier studies have shown that the time to accomplish this necessary mental rotation is proportional to the difference in alignment between the two reference systems—in this case, the difference between the direction of flight and due north (e.g., Aretz 1988, 1989; Hintzman et al. 1981).

Nevertheless, Aretz (1991) found that pilots may perform certain tasks (e.g., reconnaissance) more effectively with a north-up map. Harwood (1989) suggested that helicopter pilots should use north-up when they require absolute object location in an unfamiliar environment. These studies support our recommendation to provide both modes (north-up and track-up) as a pilot-selectable option. We also recommend providing pilot-selectable aircraft cursor positions, including both centered and 1/4-up positions, at a minimum, and possibly the 1/7-up or bottom-of-screen position as well.

4.3 Zooming Requirements

4.3.1 Description

All four demos in this category address issues pertaining to zooming the moving map display. The first demo illustrated the difference between zooming in on a particular chart series (e.g., JNC) vs. switching the chart to a new series (e.g., ONC). The second demo illustrated three variations on a 2:1 zoom: in 1 step, in 8 steps, and as a continuum (simulated with >30 steps). The third demo illustrated zoom-out capabilities. The last demo in the zoom category illustrated differences in range and legibility between the Compressed Aeronautical Chart (CAC) database in existing F/A-18 and AV-8B digital map systems and the new, joint-standard CADRG database that the TAMMAC system will employ.

In each demo, the computer played a sound bite that identified what was being displayed (e.g., "JNC, 40 nmi range;" "zooming in;" "ONC, 20 nmi range;" "zooming in;" etc.). In the last demo, the pilots were not told which movie loop displayed CAC and which displayed CADRG; the two databases were referred to as "Chart A" and "Chart B."

Demo #6: Zoom vs. Chart Series Switches: Demonstrated all aeronautical chart series currently available in the ADRG database, including GNC, JNC, ONC, TPC, JOG, and TLM-50 (Fig. 8a–f). The TLM-100 series was not available for China Lake. For each series, the demo simulated a moving map display (with the aircraft centered in north-up mode). Pilots first evaluated each individual chart series, then they evaluated the capability of zooming in on a series before switching to the next series.

Fig. 8 — Demo 6: centered, north-up displays: (a) GNC before (left, 160 nmi range) and after (right, 80 nmi range) 2:1 zoom and (b) JNC before (left, 80 nmi range) and after (right, 40 nmi range) 2:1 zoom

Demo #7: Number of Steps to Zoom: Pilots evaluated zooming into a chart by 2:1 in a single step (Fig. 9), in 8 steps (Fig. 10), and as a continuous zoom.

Demo #8: Zoom-out Capability: Pilots evaluated zooming out 2:1 over chart data (Fig. 11) and over satellite imagery (Fig. 12). Demonstrated zoom-out in a single step only.

Demo #9: Range vs. Detail/Legibility Issues: Pilots evaluated the display ranges (i.e., map coverage) of two different chart series (TPC and JOG) for the current chart database (CAC) and the new, joint-standard chart database (CADRG). Figure 13a depicts the two TPC displays, Fig. 13b depicts the JOG displays. TPC CAC data displays 20 nmi of chart coverage from top to bottom of the screen in current display systems, while TPC CADRG data would display 15.2 nmi on the same

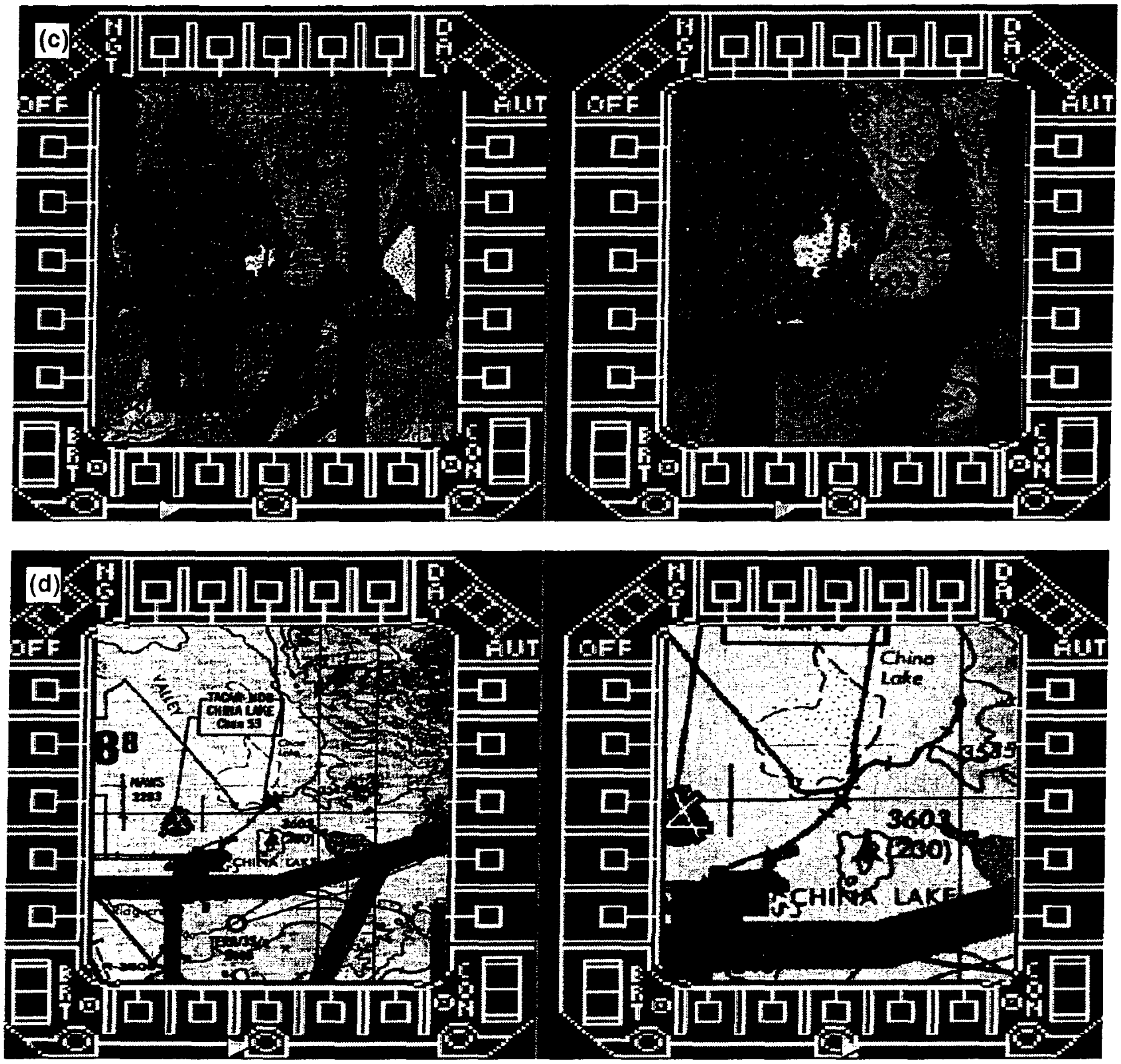

Fig. 8 — (cont.) (c) ONC before (left, 40 nmi range) and after (right, 20 nmi range) 2:1 zoom and (d) TPC before (left, 20 nmi range) and after (right, 10 nmi range) 2:1 zoom

screen. Similarly, JOG CAC displays 10 nmi on the current system, and JOG CADRG would display 7.6 nmi.

Pilots also evaluated chart feature detail and legibility for CAC and CADRG, again for both TPC and JOG series. CAC data is designed for displays with a resolution of 128 pixels per inch, while CADRG is designed to be displayed at 169 pixels per inch.

4.3.2 Results

Figure 14 summarizes the participants' responses to each individual chart series in Demo #6. Each bar represents the average rating of a given chart series, categorized by pilot group (tactical,

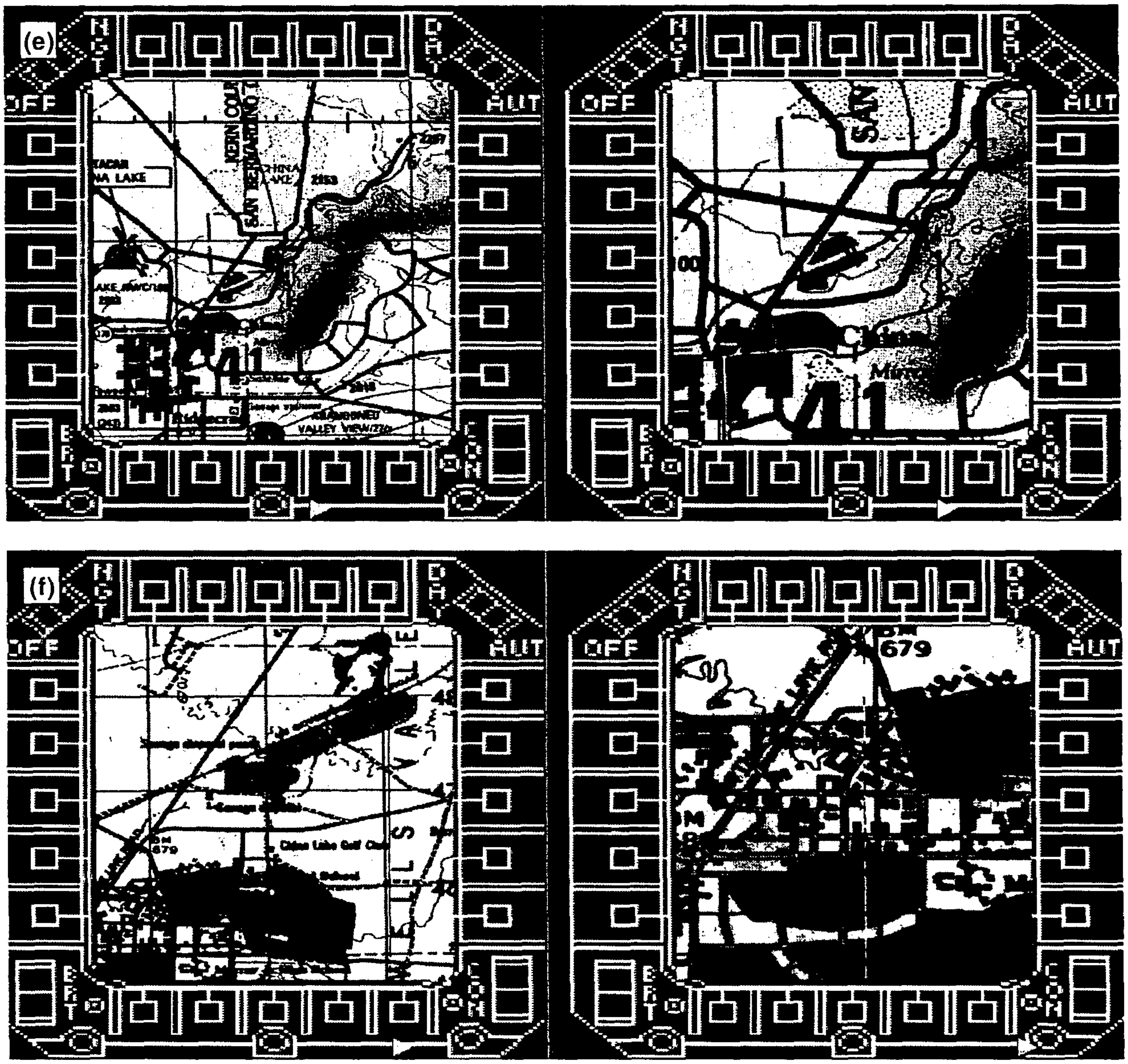

Fig. 8 — (cont.) (e) JOG before (left, 10 nmi range) and after (right, 5 nmi range) 2:1 zoom and (f) TLM-50 before (left, 2 nmi range) and after (right, 1 nmi range) 2:1 zoom

helicopter, or ASW, as listed in Table 5). The ratings range from 1 to 5, where 1 = *of no use* and 5 = *extremely useful* (see Table 1). Table 3 provides chart scales, display ranges, and other details for each chart series.

The average ratings of each chart series (regardless of pilot group) ranged between 3 (*of use*) and 5 (*extremely useful*). In order of usefulness: TPC (average rating 4.7), JOG (4.6), ONC (4.0), TLM-50 (3.7), JNC (3.5), and GNC (3.4).

Most participating pilots rated "zooming within a chart series" *of use* or better. Twelve pilots (41%) rated it *extremely useful,* and the average rating for this capability for each pilot group (tactical, helicopter, and ASW) was 4 (*of considerable use*).

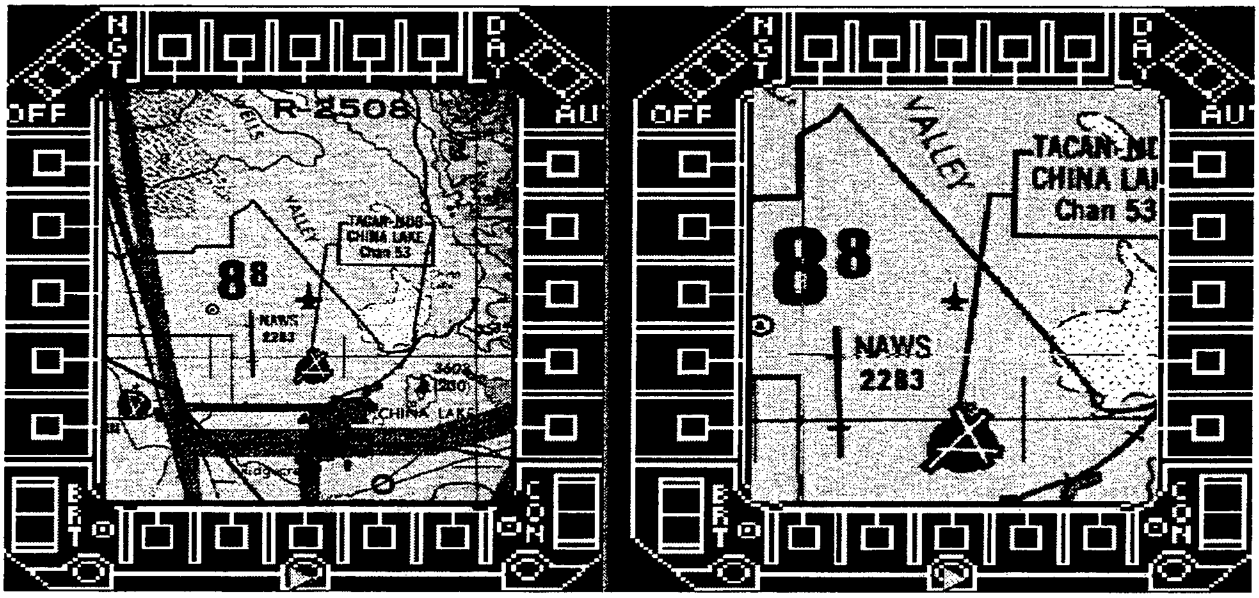

Fig. 9 — Demo 7: 2:1 zoom in a single step, TPC charts, centered, north-up displays, before (left, 20 nmi range) and after (right, 10 nmi range)

The pilots were given three choices for implementing zooms: (A) "Only zoom up to scale of next chart series, then switch series (e.g., zoom a TPC by no more than 2:1, then switch to JOG);" (B) "Allow zooms beyond scale of next chart series;" or (C) no preference. Eighteen pilots (62%) preferred option A, seven pilots (24%) preferred option B, and four pilots (14%) had no preference. Preferences varied somewhat by pilot group, as shown in Fig. 15: 12 of the 14 tactical pilots (86%) and half of the ASW pilots preferred option A; only one of each of these groups preferred B. On the other hand, only one-third of the helicopter pilots preferred option A, but more than half of this group preferred B.

Figure 16 summarizes participants' preferences with respect to number of steps to zoom (Demo #7). Most pilots preferred the continuous zoom, rating it *of considerable use* (average rating 3.9). Participants commented that a continuous zoom could "tailor the zoom factor to display the information of interest," and that it "maintained SA in a controlled, predictable, and fast manner." One participant said the continuous change allowed him to "follow the zoom" more easily, allowing him to keep track of important map features without the disorientation that sometimes occurs with large zoom increments. Conversely, a few pilots said the continuous zoom was too slow for a 2:1 scale increase. One pilot lost his "feel for the range" (i.e., the amount of map coverage displayed, in nautical miles).

The eight-step zoom was rated nearly as useful as the continuous zoom (average rating 3.6). Participants commented that it provided "more control" and avoided "inadvertently zooming in too far." Several said the eight-step was a "nice compromise between the one-step and continuous zooms." However, a few said the eight-step was labor intensive (e.g., pushing a button eight times to get a 2:1 zoom), and others disliked the potential of "overshooting" a desired zoom factor with too many button pushes if they were in a hurry. Several suggested that a four-step zoom would work better for their applications.

The one-step zoom was much less desirable than the other two zooms (average rating 2.7). Several pilots commented that it was "difficult to keep track of where everything is (on the map)

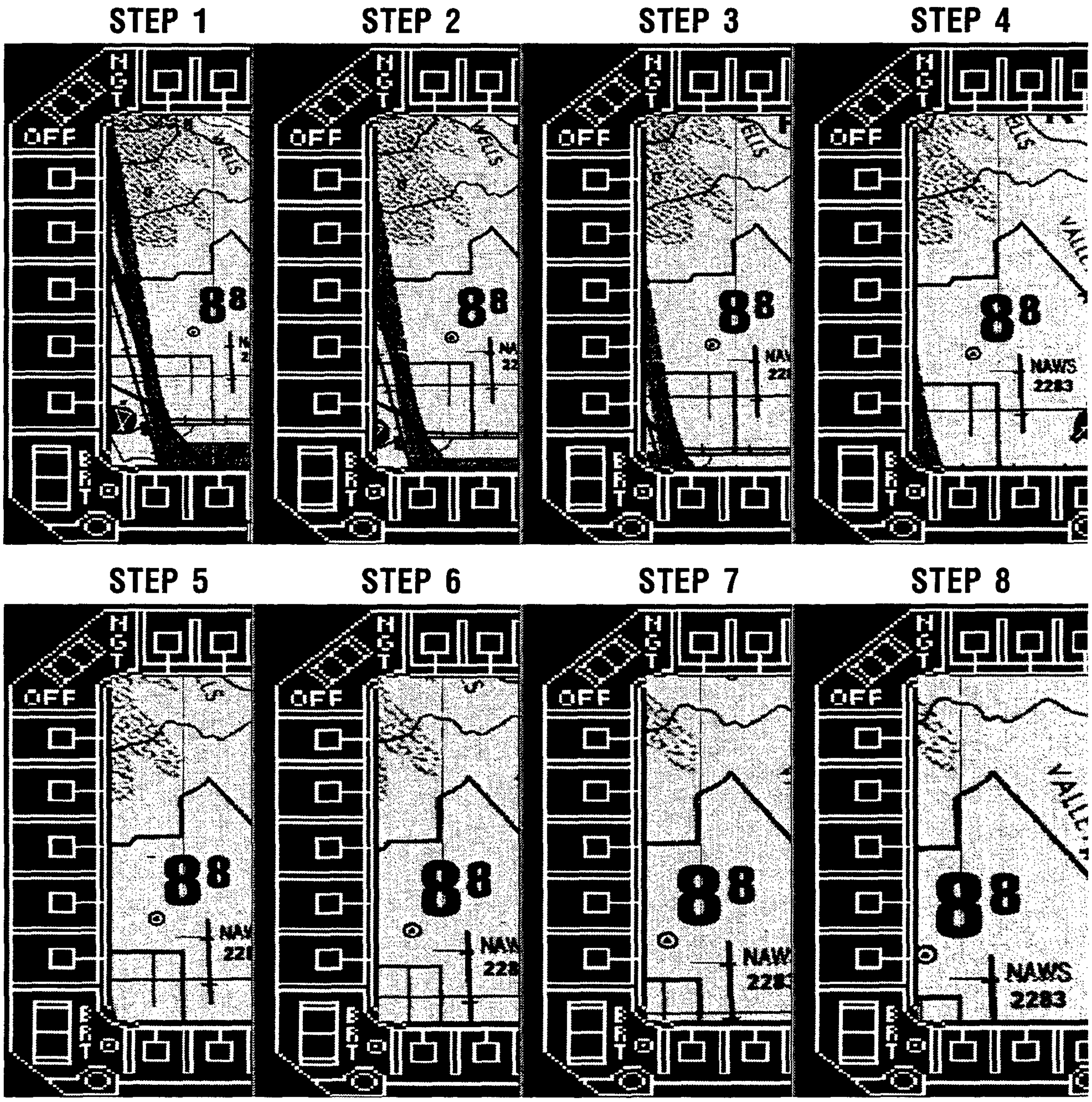

Fig. 10 — Demo 7: 2:1 zoom in eight steps, TPC charts, centered, north-up displays

and where you zoomed to." Many participants stated they would simply switch charts (e.g., from a JNC to an ONC) rather than zoom 2:1 in a single step, and others concurred that a single-step 2:1 zoom was only useful if the next-larger chart series was not available.

Pilots found a zoom-out capability to be *of considerable use* over both of the demonstrated base maps (chart and imagery). The ratings for zoom-out over both base maps were almost identical within each pilot category, so Fig. 16 shows the average ratings of zoom-out over chart and imagery for each category. Participants commented that a zoom-out capability would be very useful for getting a "quick-look" at the big picture, without having to "process a different set of reference symbols." One pilot mentioned that zooming out over a base map of satellite imagery "would be

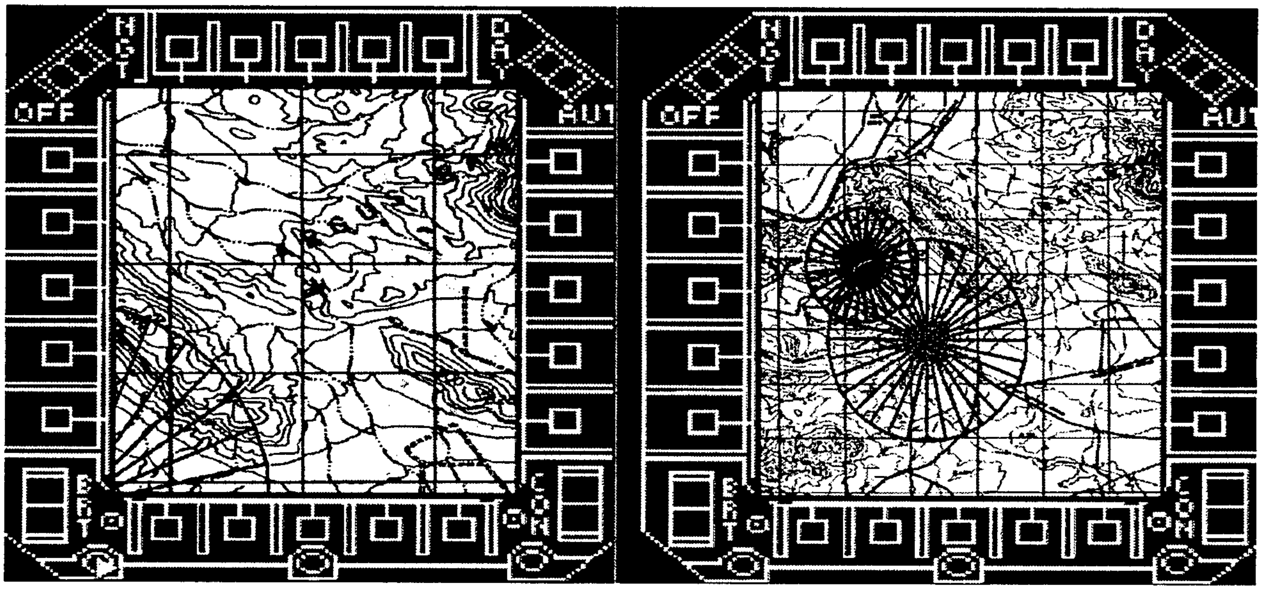

Fig. 11 — Demo 8: 2:1 zoom-out over chart (with threat ring overlays), TLM-50 charts, centered, north-up displays, original (left, 2 nmi range) and zoomed out (right, 4 nmi range)

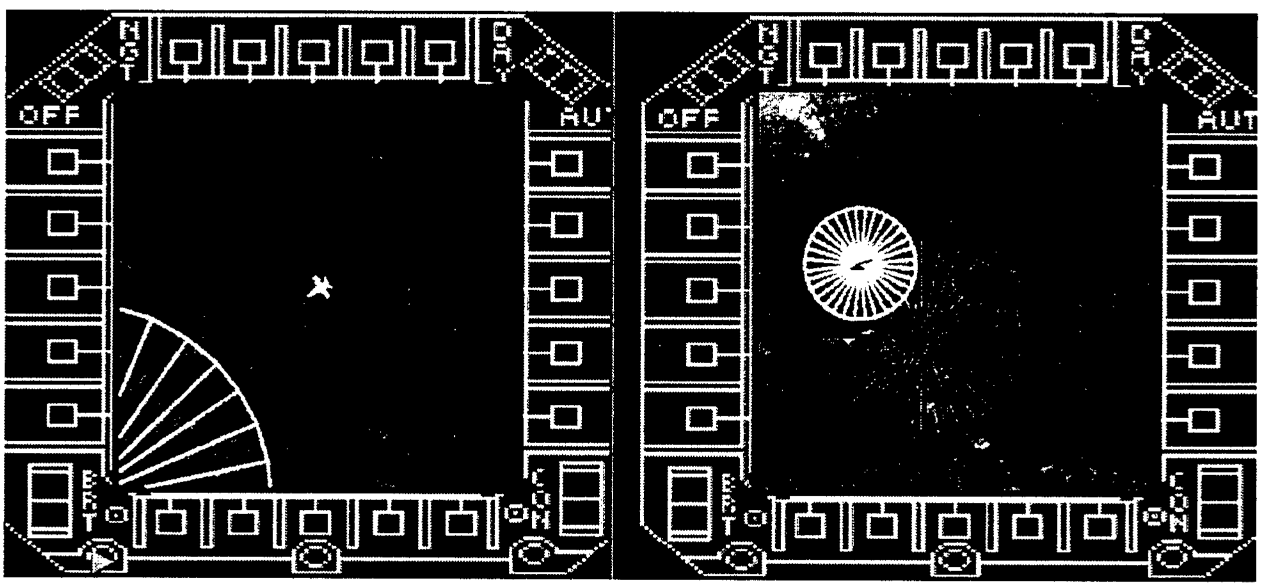

Fig. 12 — Demo 8: 2:1 zoom-out over imagery (with threat ring overlays), SPOT satellite images, centered, north-up displays, original (left, 2 nmi range) and zoomed out (right, 4 nmi range)

most useful and informative with overlays (e.g., threats, navigational symbology, etc.)." Participants listed numerous applications that would be supported by a zoom-out, including "big-picture SA;" target acquisition; flying outbound from a target; high-altitude transit (climbout); post-mission egress; mission aborts; and emergency contingencies. As in zooming in, many pilots stated they would want to be able to return to the pre-zoomed-out map display quickly, with a single button push.

Finally, pilots evaluated the differences in range (coverage) and detail (legibility) for the current chart database (CAC) and the new, joint-standard chart database (CADRG), both of which are

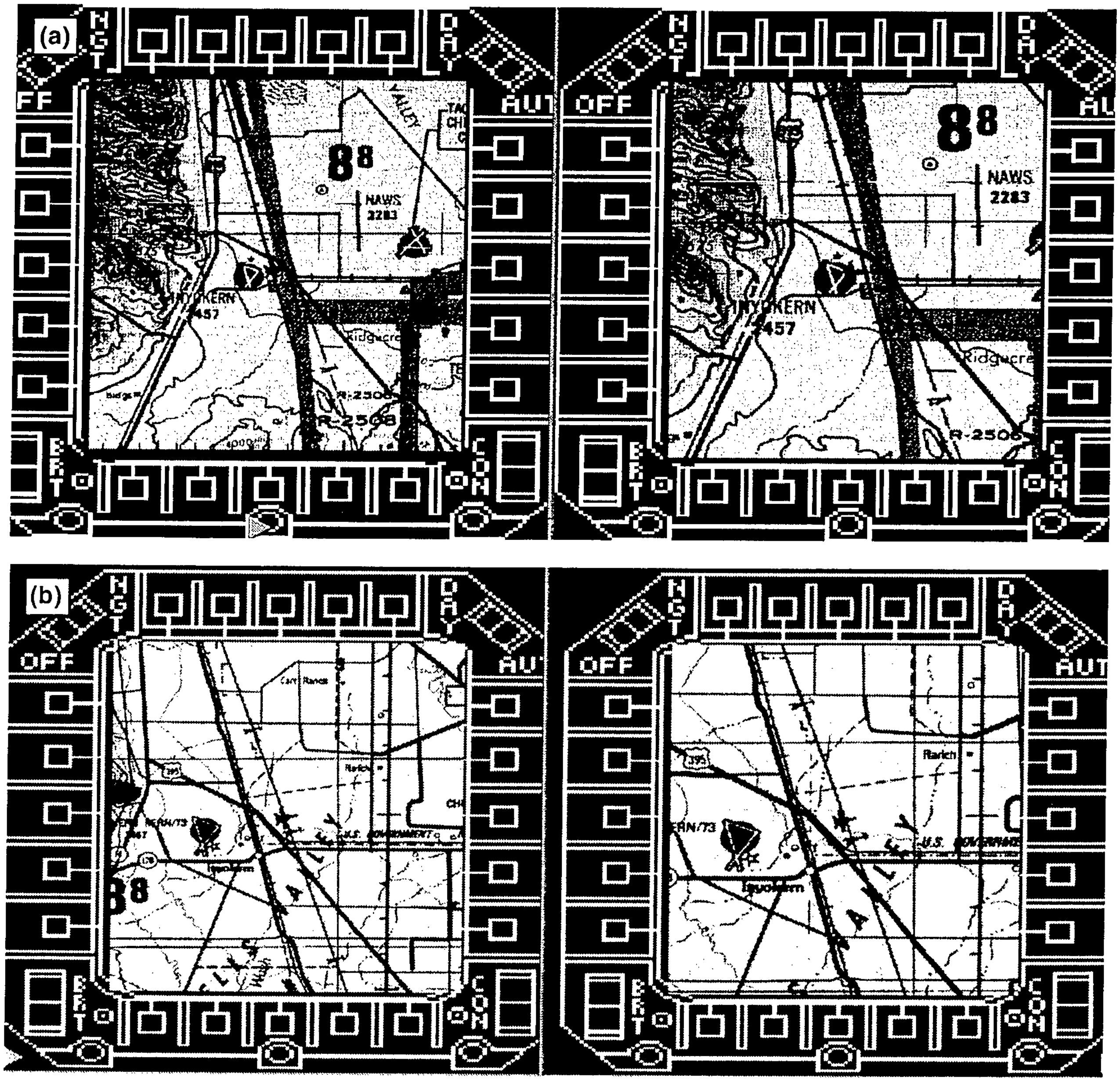

Fig. 13 — Demo 9: evaluating range and detail of current (CAC) and future (CADRG) chart databases – centered, north-up displays on current cockpit map displays: (a) TPC charts (left, CAC: 20 nmi range; right, CADRG: 15.2 nmi range) and (b) JOG charts (left, CAC: 10 nmi range; right, CADRG: 7.6 nmi range)

compressed forms of NIMA ADRG. The major differences between the two databases are resolution (CAC is stored at 128 pixels per inch, CADRG is stored at 169 pixels per inch) and compression ratio (CAC = 48:1, CADRG = 55:1). In addition, CADRG has been filtered somewhat to clarify the image. As a result, it was expected that CADRG would produce a higher quality map display than CAC, despite its greater compression ratio. However, the concern was that the higher resolution of CADRG would noticeably reduce the resultant map coverage (assuming the display screen is not upgraded). For example, CAC data for the TPC series displays 20 nmi of chart from top to bottom of the screen in current display systems, while TPC CADRG data would display 15.2 nmi on the same screen. Similarly, JOG CAC displays 10 nmi on the current system, whereas JOG CADRG would display only 7.6 nmi.

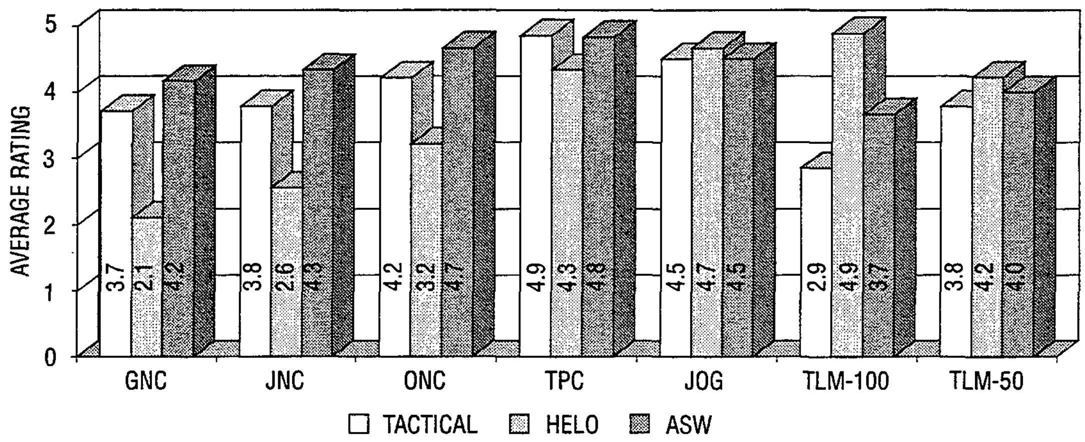

Fig. 14 — Chart series preferences

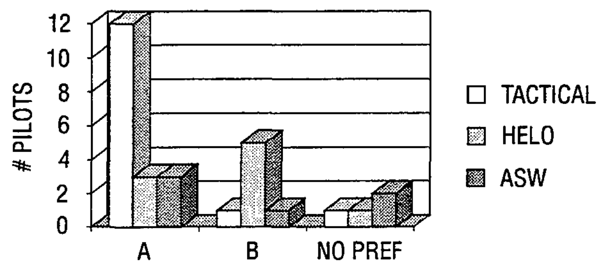

Fig. 15 — Preferences for implementing zooms: (A) only zoom up to scale of next chart series, then switch series and (B) allow zooms beyond scale of next chart series

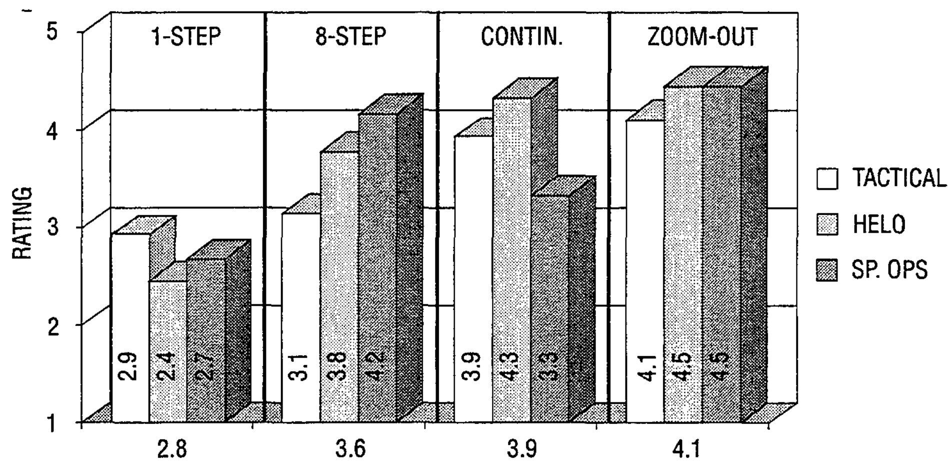

Fig. 16 — Zoom preferences

These differences in display range must be taken into consideration when designing the new cockpit displays. Therefore, we asked pilots to evaluate the geographic range (map coverage) and chart detail (legibility) for CAC and CADRG first using TPCs then JOGs. As shown in Fig. 17, 70% of surveyed pilots preferred CAC over CADRG to provide optimum range for both TPC and JOG series. Only 10% of pilots preferred CADRG for optimum range and 20% had no preference.

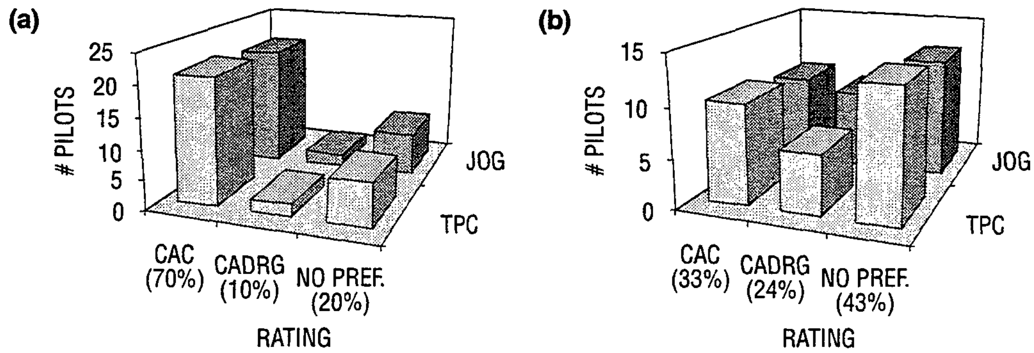

Fig. 17 — Preferences for (a) chart range and (b) chart legibility

For chart detail and legibility, 33% of pilots preferred CAC, 24% preferred CADRG, and 43% had no preference.

Chart type A, which was the current chart database (CAC), was clearly preferred over type B (CADRG) with respect to geographic range and map coverage. However, there was no significant preference for one chart type with respect to detail and legibility.

4.3.3 Summary and Recommendations

Based on the results of these surveys, implementing the following zoom options is recommended: a continuous zoom-in (with a wheel control), a four-step, 2:1 zoom-in (as opposed to eight-step or one-step zooms), and a one-step 2:1 zoom-out. The four-step zoom-in should allow "buffered button pushing" so the pilot could hit the zoom-in button quickly four times and the display would "catch-up" with stepped zooms. This seems to be a good compromise among all the pilots' stated requirements for controlled zooms, constant SA, rapid implementation, and minimum pilot workload. Whether using the continuous or stepped-zoom option, the pilot needs to be able to return to the original scale with a single button push. If all of these zoom options would be too expensive to implement initially, then omitting the continuous zoom is recommended until it is feasible.

Zooms in either direction (in or out) should only be permitted to the next available chart series, at which point the computer should automatically switch series. Therefore, the computer will need to "know" which chart series have been loaded in the cockpit moving map computer.

Finally, the altered map coverage of CADRG (as compared to CAC) must be considered in the moving map display. One option would be to make the new display about 1.3 times larger (about 5.3″ square, compared to the current 4″) to accommodate the increased resolution of CADRG. If the display will not be upgraded in TAMMAC, then consider zooming out CADRG by about 0.8:1 to ensure adequate map coverage on the screen. Pilots are accustomed to having a full 20 nmi of coverage when they choose TPC (for example). In fact, they typically refer to a chart series in terms of its coverage (i.e., TPC is referred to as a "20 nmi chart.") It would be confusing and potentially dangerous to display 15.2 nmi coverage for a TPC when pilots are conditioned to viewing 20 nmi. Pilots also commented (in the taped interviews) on the usefulness of having an integer range value (e.g., 10 nmi, 20 nmi, 40 nmi, etc.) and that it would be more difficult to calculate distances on-the-fly with non-integer values (e.g., 7.6 nmi, 15.2 nmi, 30.4 nmi, etc.).

4.4 Terrain Elevation Data

4.4.1 Description

Demo #10: Contour Lines vs. Shaded Contours: Four different terrain elevation maps were demonstrated: contour lines and gray-shaded contours in 2-D (Fig. 18a,b) and in 3-D (Fig. 18c,d). Contour lines were drawn at 32-m contour intervals, and gray-shaded contour maps depicted up to 16 gray levels. Participants were not informed of these values. Aircraft program preferences for contour intervals are summarized in App. B (item 43), but there are no stated preferences for the number of gray-shading levels.

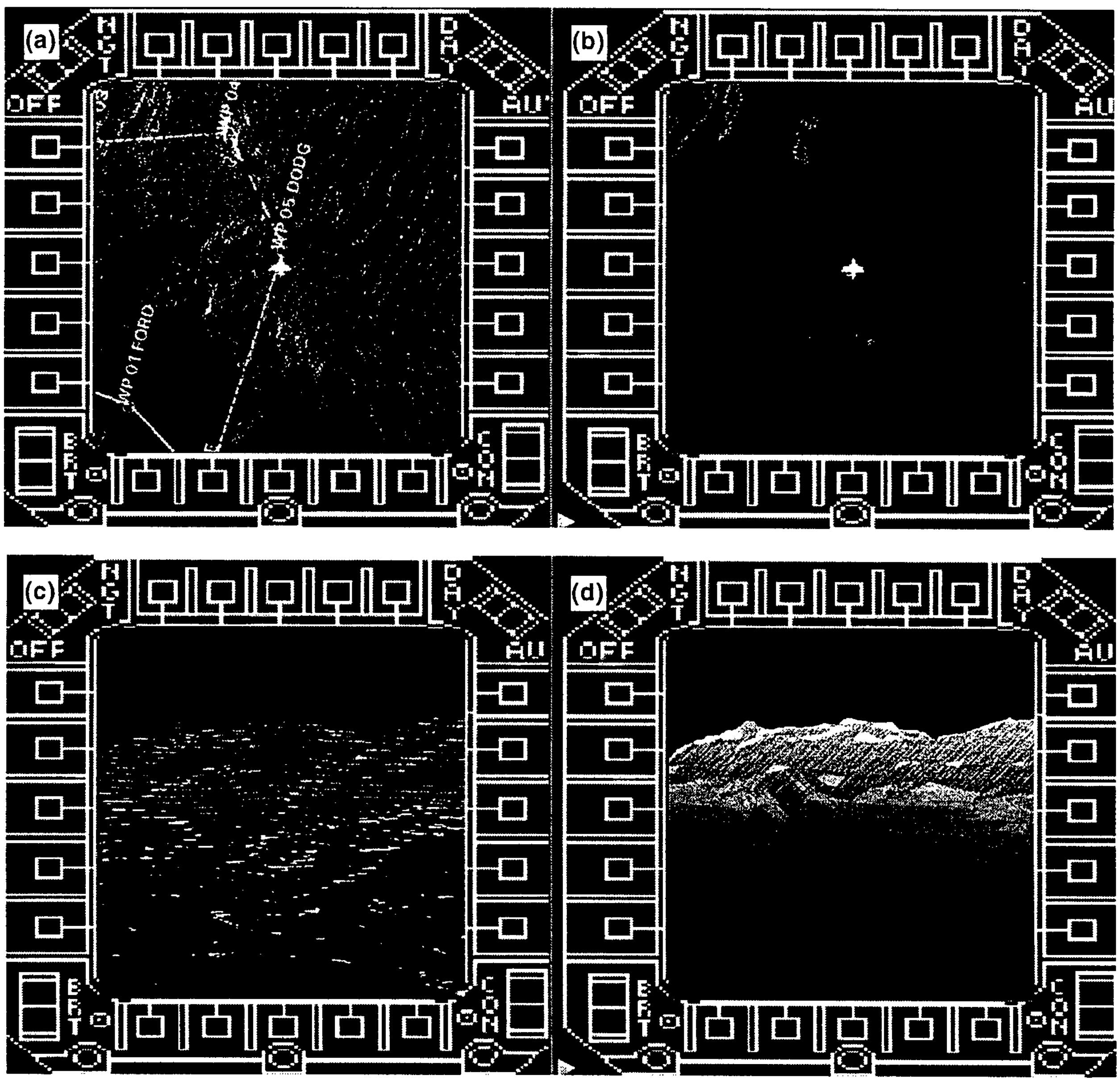

Fig. 18 — Demo 10: evaluating two presentations of terrain data, contour lines vs. shaded contours. All include height-above-terrain overlays, DTED (yellow = aircraft altitude ±16 m; red = all altitudes above yellow): 2-D, centered display, track-up ((a) 32 m; (b) 16 gray levels) and 3-D, perspective-view display ((c) 32 m; (d) 16 gray levels).

Demo #11: Contour Intervals: Four different contour intervals for terrain elevations were demonstrated: 100 ft, 32 m, 64 m, and 128 m (Fig. 19a–d). These values were taken from the TAMMAC Requirements Database (summarized in App. B, item 43), in which the V-22 program stated a requirement for contour intervals ranging from 16 to 128 m, and TAMMAC stated a requirement for 100 ft. We were unable to process 16 m contour intervals for the selected area of coverage because the density of lines was too great for the software (ArcInfo) to handle at the range being displayed (10 nmi). Participants were not told what the contour intervals were; they simply viewed individual movies that were labeled "Contour Interval A," "... B," "... C," and "... D."

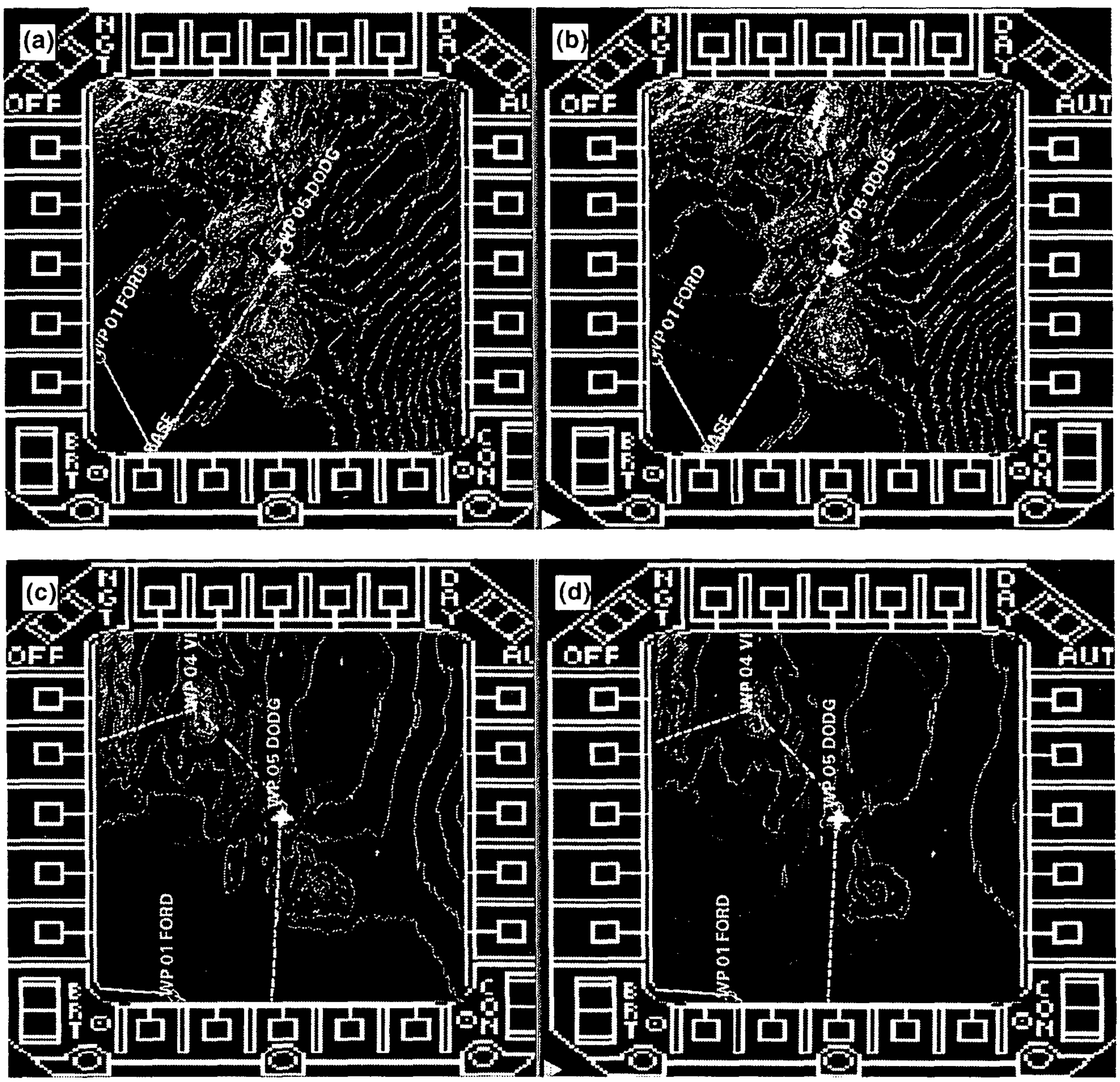

Fig. 19 — Demo 11: evaluating different contour intervals for terrain data (10 nmi range), DTED, centered display, track-up: (a) 100 ft; (b) 32 m; (c) 64 m; and (d) 128 m

Demo #12: Sun-Angle Shading (2-D and 3-D): Several sun-angle-shaded terrain maps in 2-D and 3-D were demonstrated. For 2-D sun-angle shading, we compared displays using 8 vs. 15 gray levels (Fig. 20). Participants were asked to select which half of one continuous movie they preferred: the first half, which used eight gray levels, or the second half, which used 15 levels. Alternatively, they could select "no preference." It was not divulged how many gray levels were represented in each half.

For the 3-D sun-angle-shaded terrain, displays were compared using 15° sun-angle increments (i.e., 13 steps from 0° to 180°: 0°, 15°, 30°, 45°, ... 180°) vs. 1° increments (i.e., 181 steps: 0°, 1°, 2°, 3°, ... 180°). Figures 21a–d illustrate shaded terrain for four sample sun angles: 30°, 75°, 105°, and 150°, which would approximate 8 a.m., 11 a.m., 1 p.m., and 4 p.m. (assuming a 6 a.m. sunrise and 6 p.m. sunset). Participants were asked to select which model they preferred: "Movie A," which used 15° increments or "Movie B," which used 1° increments.

4.2.2 Results

Figure 22 presents aircrew ratings for three different terrain elevation maps: contour lines, gray-shaded contours, and sun-angle shading, in both 2-D (planimetric) and 3-D (perspective) views. The first four histogram sets in Fig. 22 present results of Demo 10 (contour lines vs. gray-shaded contours), and the last two sets present results of Demo 12 (sun-angle-shaded terrain).

Terrain map types: As shown in Fig. 22, participants consistently preferred sun-angle-shaded terrain maps over both contour lines and gray-shaded contours. Most participants ranked gray-shaded contours as their second choice. Participants rated contour lines last, with the exception of helicopter pilots, who preferred contour lines over shaded contours (in the 2-D view only).

Most participants did not show an overwhelming preference for 2-D vs. 3-D views of terrain. Tactical pilots showed no preference at all for 2-D vs. 3-D contours (lines or gray-shaded), but they

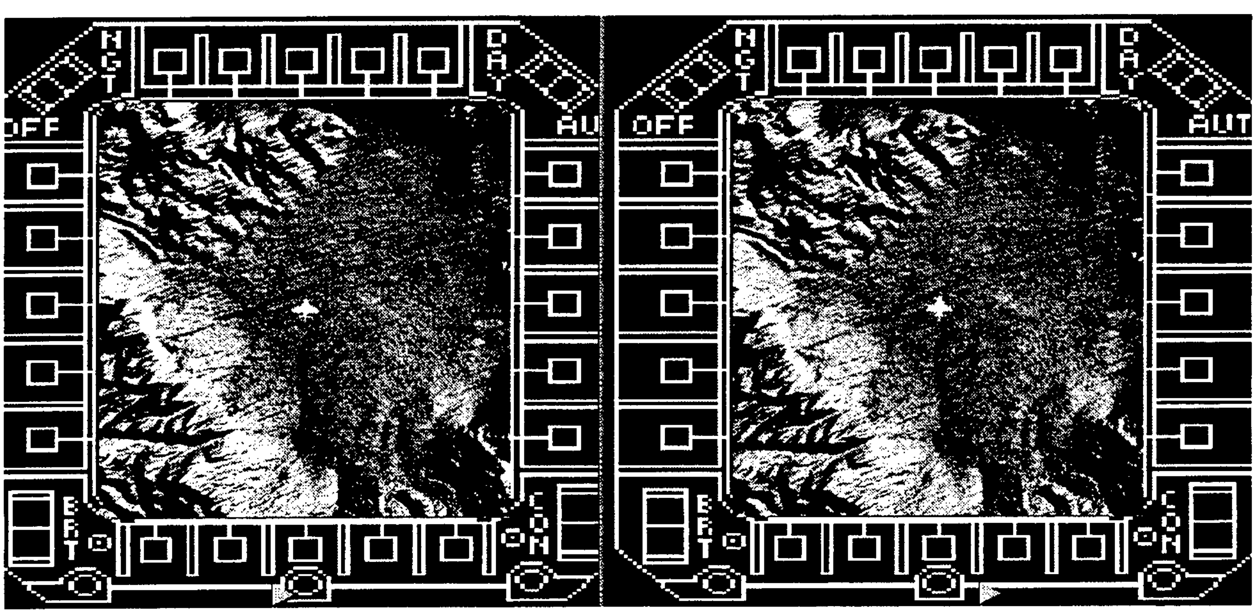

Fig. 20 — Demo 12: evaluating 2-D sun-angle-shaded terrain data (10 nmi range, DTED, centered display, track-up) using 8 gray levels (left) and 15 gray levels (right)

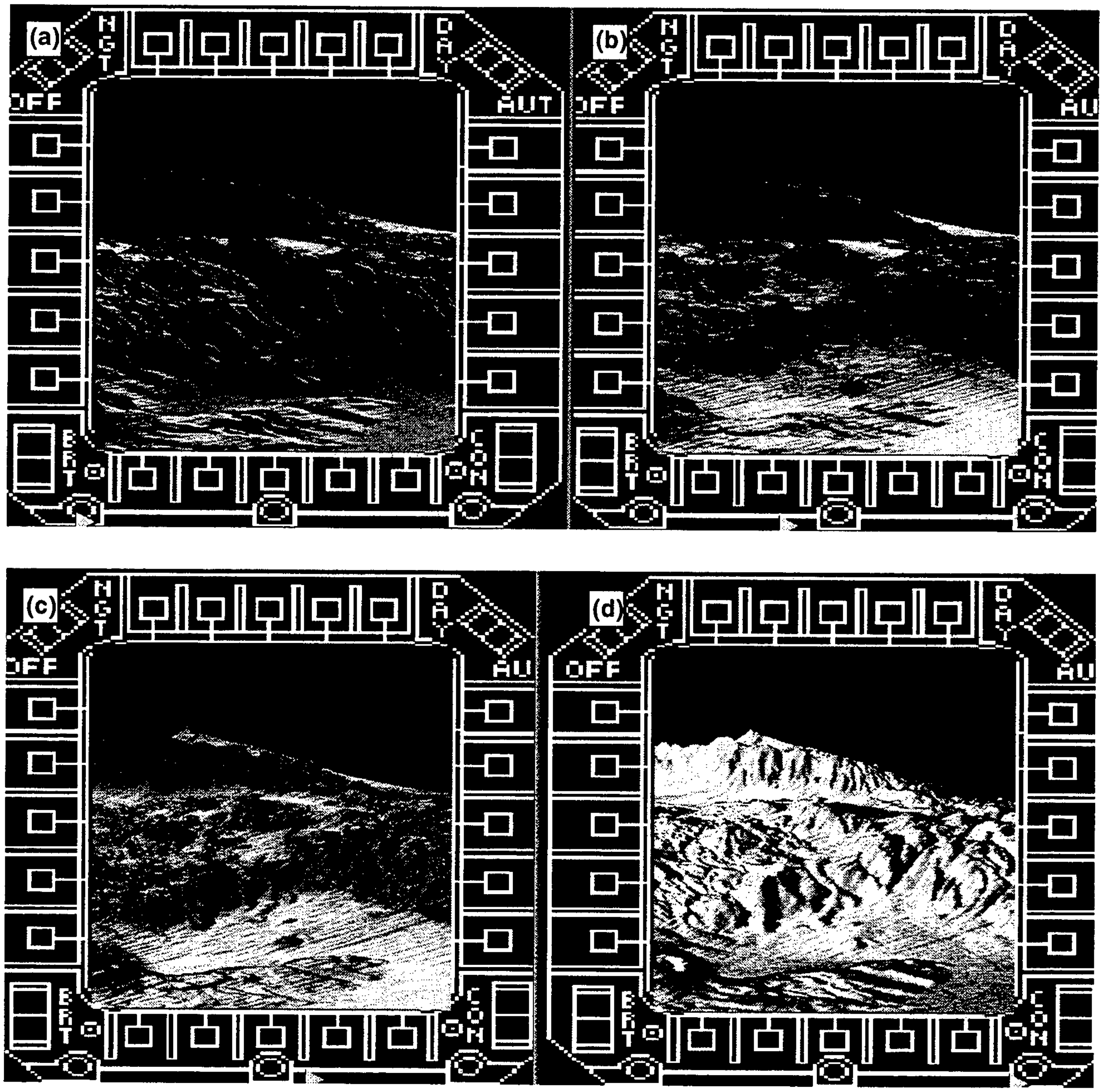

Fig. 21 — Demo 12: evaluating 3-D sun-angle-shaded terrain data (DTED, perspective view display). Times shown are based on 6 a.m. sunrise (0° sun angle), 6 p.m. sunset (180° sun angle), and sun directly overhead at noon (90° sun angle): (a) 8 a.m., 30° angle; (b) 11 a.m., 75° angle; (c) 1 p.m., 105° angle; and (d) 4 p.m., 150° angle.

preferred 3-D over 2-D for sun-angle shading. Helicopter pilots preferred 2-D over 3-D for contour lines, but they preferred 3-D over 2-D for both gray-shaded maps and sun-angle shading. ASW pilots preferred 3-D over 2-D for both contour maps and gray-shaded maps, but they showed no preference at all for 2-D vs. 3-D sun-angle-shaded maps.

Overall, participants rated both 2-D and 3-D contours *not very useful* (except helicopter pilots, who rated 2-D contours *of use*). Participants rated 2-D and 3-D gray-shaded terrain maps *of use* and *of considerable use*, respectively, and they rated both 2-D and 3-D sun-angle-shaded terrain maps *of considerable use*.

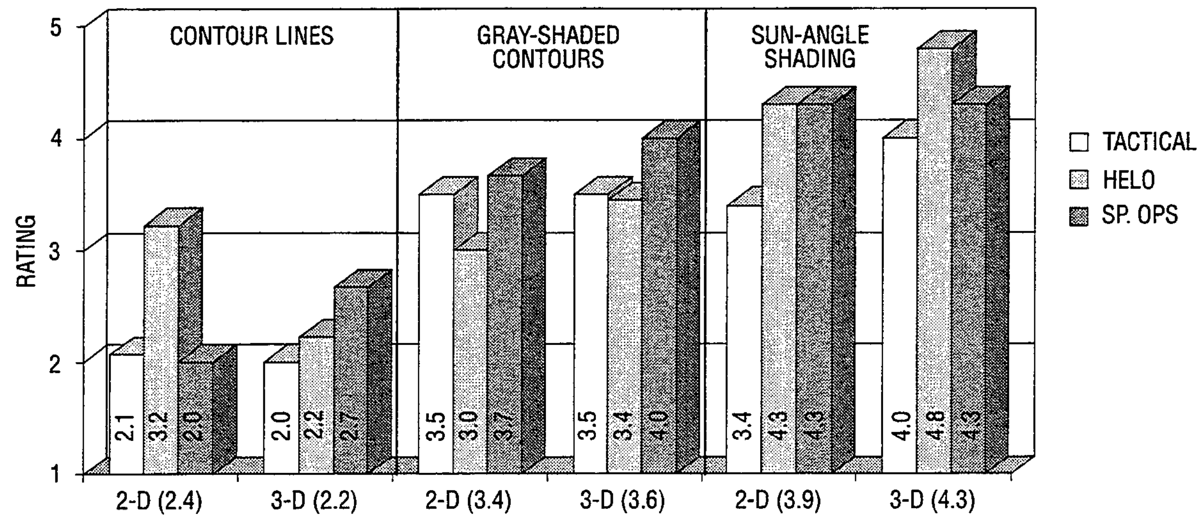

Fig. 22 — Preferences for terrain elevation map types (Demos #10 and #12)

Participants' comments clarify why the majority preferred sun-angle-shaded terrain over other models. Tactical and ASW participants cited enhanced SA and anticipation of hazards:

- "Excellent SA builder for flying in terrain; gives a feel for terrain and potential hiding spots."
- "Increases SA and ability to develop an evasive plan and anticipate likely threat locations."
- 2-D useful for recognizing distant terrain and even doing radar interpretation. 3-D extremely useful when flying low altitudes and collating (the) display to outside world."
- "Allows me to anticipate rising terrain easily in times of poor weather or at night."
- "Best if sun angle corresponds to actual time of day. Would help in target area recognition."

Six of the 15 participating tactical pilots stated that sun-angle-shaded terrain displays would be useful for pre-flight and mission planning, as well as in-flight navigation.

Seven of the nine participating helicopter pilots cited the sun-angle-shaded display's realistic appearance:

- "Presents terrain information to the pilot clearly ... as it might appear to him out of the cockpit."
- "Day or night: superb! Allows you to see what terrain may be obscured due to shadowing, and if you can find a hiding place ... This capability allows you to more effectively plan your tactics, leaving less to guesswork. Being able to see what an area will look like is very useful."
- "(For) terrain orientation, determining hidden obstacles ... and checkpoints at night on night vision goggles."

Four helicopter pilots suggested that moon-angle shading would be useful, as well as sun angles. Processing moon-angle shading would be equivalent to processing sun angles, since the computer simply operates on a generic light source.

At least one participant would prefer to "freeze" the shading at some optimum sun angle to provide the most detail, rather than shade the terrain according to the actual flight time. He stated in a taped interview, "as you change the sun angle, (the display) really washes out (which is) the way it is in the real world. But if I knew what was *really* there, that may give me more insight into what I can do." When asked if he might be disoriented by seeing one sun angle out of the cockpit window and another on the display, the pilot replied, "I don't know, but I'd love to go fly it and find out!" Such comments reinforce a need to rigorously flight-test these capabilities in simulators or trainers and define exactly how they will be utilized so the final implementation will best meet user demands.

Participants were less impressed with contour lines and gray-shaded contours; six of 15 tactical pilots cited interpretability and ease of use as major criteria for rating terrain maps. One participant stated: "Both 3-D models (contour lines and gray-shading) were very difficult to interpret and use;" another stated: "Gray shading was much easier to interpret (than contour lines)." Two ASW participants described the contour line displays as "cluttered." Several tactical pilots suggested there might be more potential for these displays if they were rendered with greater resolution (this might require higher resolution terrain data): "The gray shading could have been useful if it didn't look so blocky;" "Gray-shaded 3-D terrain needs better resolution; it could be useful for low altitude navigation and terrain avoidance."

Most helicopter pilots preferred contour lines over gray-shaded terrain, probably because, as one pilot explained, "contour lines are more familiar" to this group. Two helicopter pilots suggested that some combination of shading and contours would be preferable. However, several helicopter pilots mentioned that none of these displays conveyed "depth" or the "terrain's shape" very well, making it difficult for them to "pick a proper valley and landing zone."

The following paragraphs address more specific issues for three of the terrain displays: preferred number of contour intervals (for contour line displays), number of gray levels (for 2-D sun-angle displays), and number of sun-angle increments (for 3-D sun-angle displays).

Contour Intervals: As shown in Fig. 23, participants rated most contour intervals *not very useful* or *of use*, with the exception of helicopter pilots, who rated 32-m contours *of considerable use*. On average, all three groups (i.e., tactical, helicopter, and ASW) rated 64-m contour intervals *of use* and 128-m intervals slightly lower. Each group rated 32-m contours slightly higher than 100-ft contours, even though the contour values (32 m and 100 ft) are very close and produce almost identical contour charts. The preference is probably due to the fact that the 32-m display included a Height Above Terrain (HAT) model, in which a yellow overlay represented all terrain elevations at the aircraft altitude ±16 m and a red overlay represented all elevations above that. The

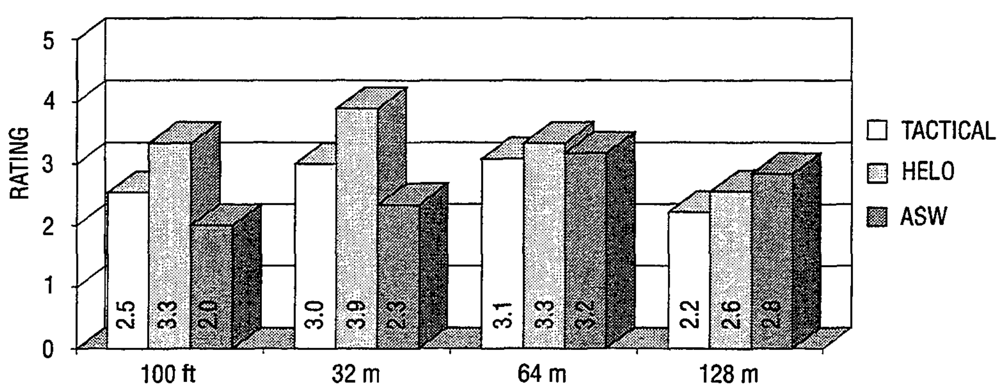

Fig. 23 — Preferences for number of contour intervals in contour line displays (Demo #11)

100-ft contour chart did not include HAT. A later section of this report discusses HAT overlays in more detail (Demo #13 in the Overlay Data section).

Number of Gray Levels for 2-D Sun-Angle Shading: As shown in Table 12, only one participant showed any preference for 8 vs. 15 levels of gray in the 2-D sun-angle-shaded terrain data. However, this lack of preference could change depending on the variability of the data. The region of China Lake that was displayed is relatively flat, with only minor elevation changes around the edges (Fig. 20). In a region with greater terrain variance, the number of gray levels required for a realistic scene may be more significant. For example, Foley and Van Dam (1984, p. 594) demonstrated that 64 gray levels were required to adequately represent one continuous-tone, black-and-white photograph (where "adequate" meant that the resultant image appeared to be continuous, with no visible contouring between the gray shades).

Other images might require more than 64 gray levels, depending on the variance of the data and the desired result. Some contour effects are probably acceptable in sun-angle-shaded terrain displays, and for most of these displays, eight shades of gray are probably sufficient. Nevertheless, several gray levels (e.g., 8, 16, 32) for various regions (e.g., flat, hilly, very mountainous) should be evaluated before making any final recommendations about the number of gray levels required for satisfactory sun-angle-shaded terrain in cockpit moving map displays.

Sun-Angle Increments for 3-D Sun-Angle Shading: As shown in Fig. 24, most pilots preferred the sun-angle-shaded terrain model with 1° increments, which provided a continuous transition in shadows and lighting from sunrise to sunset. Several participants preferred the more discrete model with 15° increments, and several others indicated no preference. A few pilots indicated that 1° increments were unnecessary or superfluous.

4.4.3 Summary and Recommendations

Based on these results, the implementation of sun-angle- (and moon-angle-) shaded terrain maps in both 2-D and 3-D is highly recommended. Pilots should have a choice between viewing a preset, "ideal" sun angle (which could be set in mission planning) or viewing the terrain display with a true sun angle that would change dynamically in flight with the time of day. Most participants judged contour lines and gray-shaded contour charts to be too confusing, too cluttered, and too hard

Table 12 — Preferences for Number of Gray Levels in 2-D Sun-Angle-Shaded Displays (Demo #12)

	# GRAY LEVELS		
	8	15	N/P
Tactical	1	0	13
Helo	0	0	9
ASW	0	0	6
Totals	1	0	28

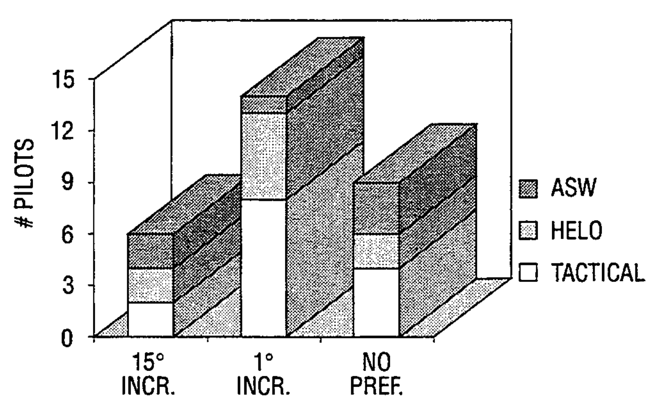

Fig. 24 — Preferences for sun-angle increments in 3-D sun-angle-shaded displays (Demo #12)

to interpret for most applications. (We concede, however, that our contour lines and gray-shaded contours could be improved with superior computer graphics software.)

It is important to consider the vertical accuracy of the source terrain data when determining optimal contour intervals. According to the NIMA publication *Digitizing the Future* (NIMA 1996), "the information content of DTED is approximately equivalent to the contour information represented on a 1:250,000 scale map. Exploitation at larger scales must consider each individual cell's accuracy evaluation." In addition, NIMA's accuracy objectives for DTED are as follows: "absolute vertical accuracy (i.e., the uncertainty in elevation of a point with respect to Mean Sea Level) of ±30 m, and absolute horizontal accuracy (i.e., the uncertainty in horizontal position of a point with respect to the current World Geodetic System) of ±50 m." These are *objectives*; the DTED Product Specification (NIMA 1986) gives an absolute horizontal accuracy of ±130 m (the DTED Specification cites the same absolute vertical accuracy of ±30 m as *Digitizing the Future*). These values suggest that contour lines plotted at intervals closer than 30 m would give a false impression of vertical accuracy (i.e., elevation) for this data set, and contour lines closer than 50–130 m may give a false impression of horizontal accuracy (i.e., geographic position on the Earth) for this data set.

Sun-angle-shaded terrain displays might also present a false impression of accuracy, and pilots should be cautioned. However, it is suggested that there is an intuitive difference between viewing terrain data as a discrete series of contours, which by their very nature imply a certain degree of accuracy, vs. a rendered surface (such as the sun-angle-shaded model), which looks more realistic but does not necessarily imply the same absolute accuracy.

4.5 Overlay Data

4.5.1 Description

The next three demos examined pilots' responses to different types of new, mission-specific information overlaid on traditional charts and imagery. Three different kinds of mission information are illustrated in this set of demos: Height-Above-Terrain (HAT), Clear Line Of Sight (CLOS), and threat intervisibility (e.g., threat rings).

Demo #13: HAT Over Chart or Imagery: Evaluated usefulness of displaying bi-color HAT overlays in which a yellow overlay denoted terrain elevations at the aircraft altitude ±16 m and a red overlay denoted all terrain elevations above that. Demo #13 displayed HAT over chart data in 2-D and 3-D (Fig. 25a), HAT over terrain data as 2-D contour lines and 3-D gridded mesh (Fig. 25b), and HAT over satellite imagery in 3-D only (Fig. 25c). The same model could be used to display other HAT types, including Height-Above-Threshold, -Target, or -Touchdown. This coloration was intended to reduce pilot workload in interpreting contours, shaded elevations, and hypsographic tinting.

Demo #14: CLOS Over Imagery: Evaluated the usefulness of a CLOS model using two display windows (Fig. 26). The larger upper window simulated a moving map of satellite imagery overlaid by a threat ring, with the aircraft cursor centered over a north-up display. The aircraft and threat symbols were highly visible over the satellite imagery in this view. The bottom window displayed a profile of the terrain between the threat and the aircraft (in this case, a helicopter). At the start of the demo, the helicopter was hidden behind a mountain, then it ascended to bring the threat in sight. As soon as the threat was in sight of the aircraft, a red line appeared (in both views) connecting the aircraft and threat symbols.

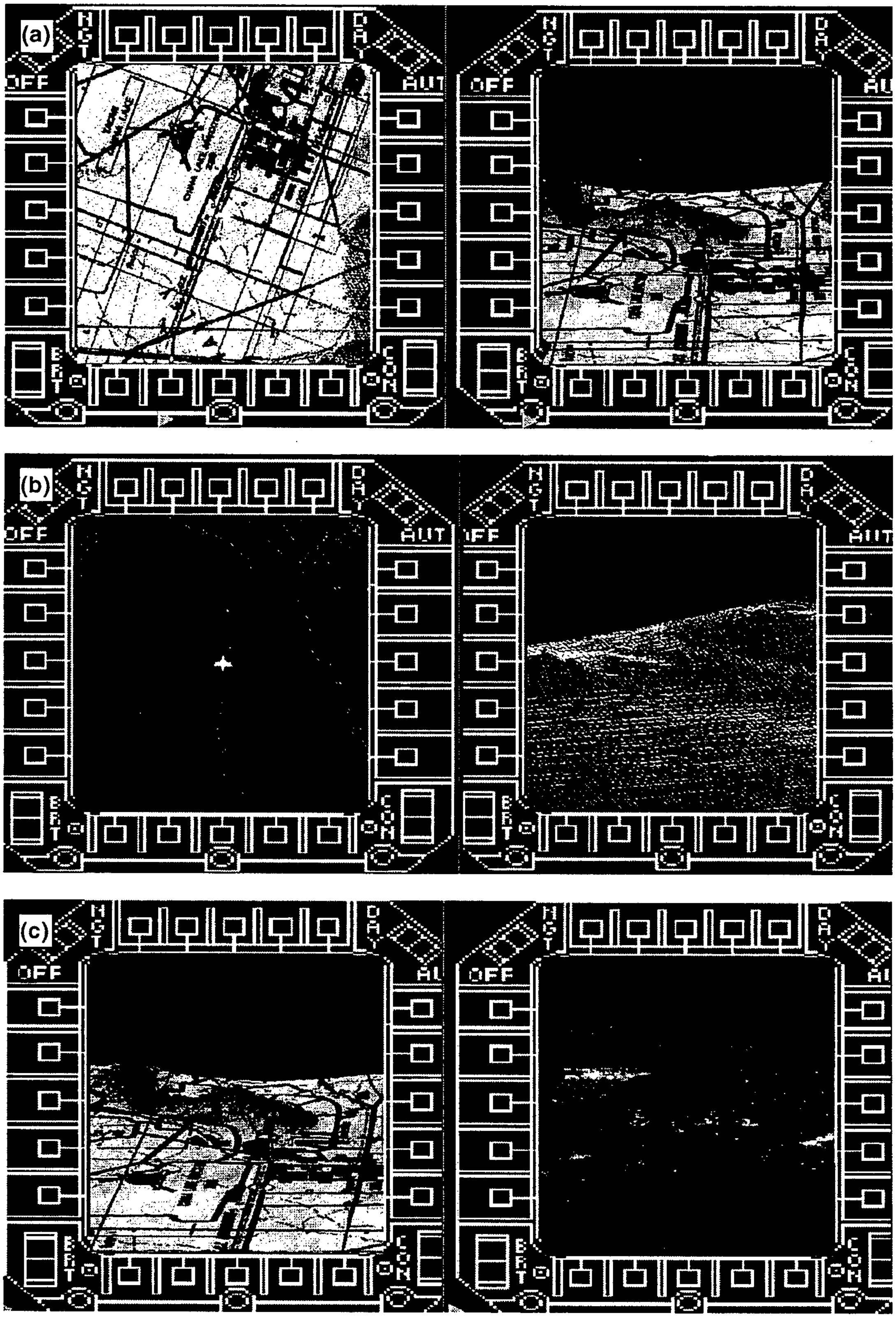

Fig. 25 — Demo 13: evaluating HAT in 2-D (left-side plots, centered display, track-up) and 3-D views (right-side plots, perspective view). Yellow overlay = elevations at aircraft altitude of ±16 m; red overlay = elevations higher than aircraft altitude: (a) chart data (JOG), (b) terrain data (DTED), and (c) HAT overlaid on chart data and satellite imagery, chart data (JOG, left) and satellite imagery (SPOT, right).

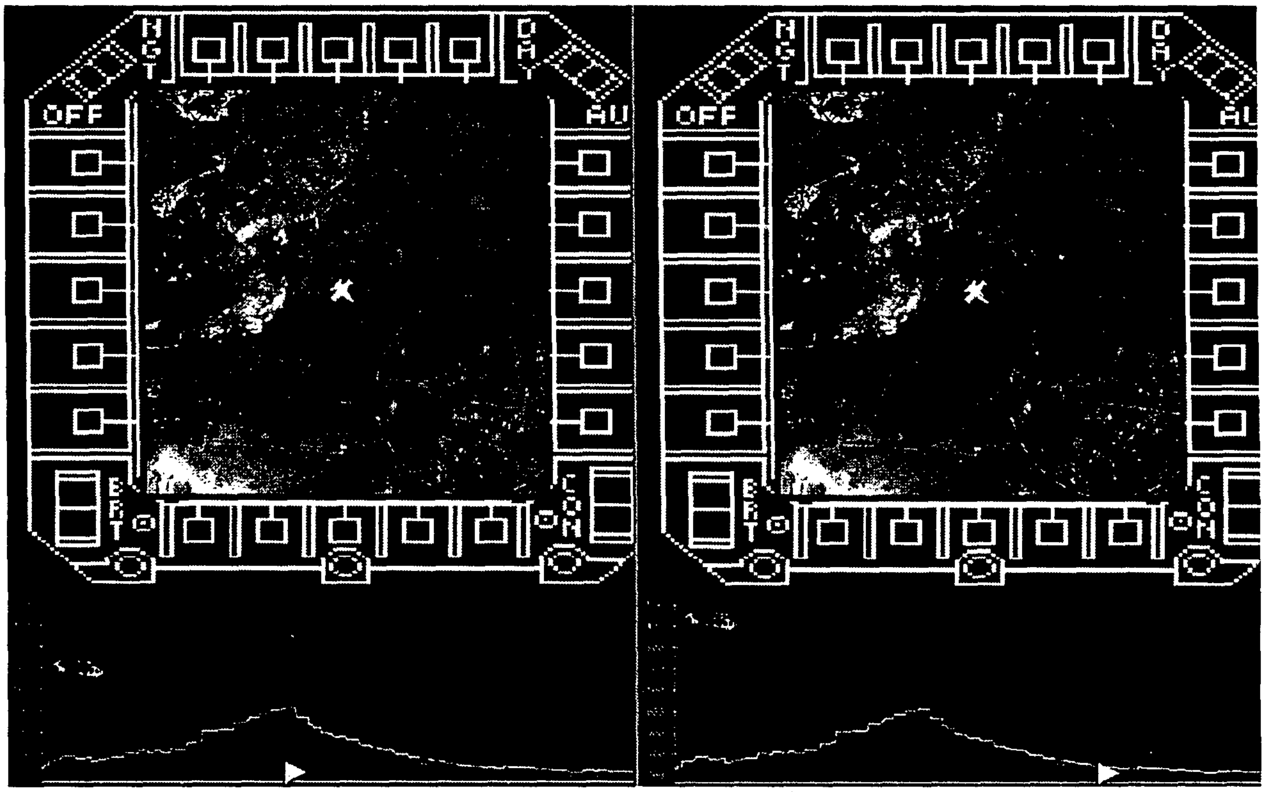

Fig. 26 — Demo 14: Clear (or Calculated) Line-Of-Sight (CLOS) with satellite imagery for base map, target out of sight (left) and in sight (right)

Demo #15: Threat Intervisibility: Evaluated four different ways of depicting threats over chart and imagery: threat rings (Fig. 27a, b), pseudo-transparent hatched overlays (Fig. 27c, d), threat rings with spokes (Fig. 27e, f), and a 3-D threat dome (Fig. 27 g, h). For each representation, the moving map depicted the aircraft flying into the threat area, at which point the white aircraft cursor and the yellow threat symbol changed color to red to indicate danger.

4.5.2 Results

Figure 28 reflects participants' ratings of HAT over various base maps. Pilots rated HAT over imagery highest overall, with only one response below a score of 3 (*of use*). This may be due in part to the high visual contrast between the black-and-white imagery and the red-and-yellow HAT colors, which made interpretation particularly easy.

Responses to HAT shading over aeronautical charts were also favorable. Some participants commented that the HAT symbology would be useful for both terrain masking and terrain avoidance. Difficulty in interpretation sometimes arose when HAT colors blended with similar chart colors or obscured important chart information. The 3-D (perspective) view of HAT over chart data was slightly favored over the comparable 2-D (planimetric) view, despite (or perhaps because of) the relative novelty of 3-D chart displays to many participants.

In contrast, displaying HAT over a contour-line elevation map proved to be the least effective way to provide terrain clearance information to pilots. The lack of additional cartography to provide

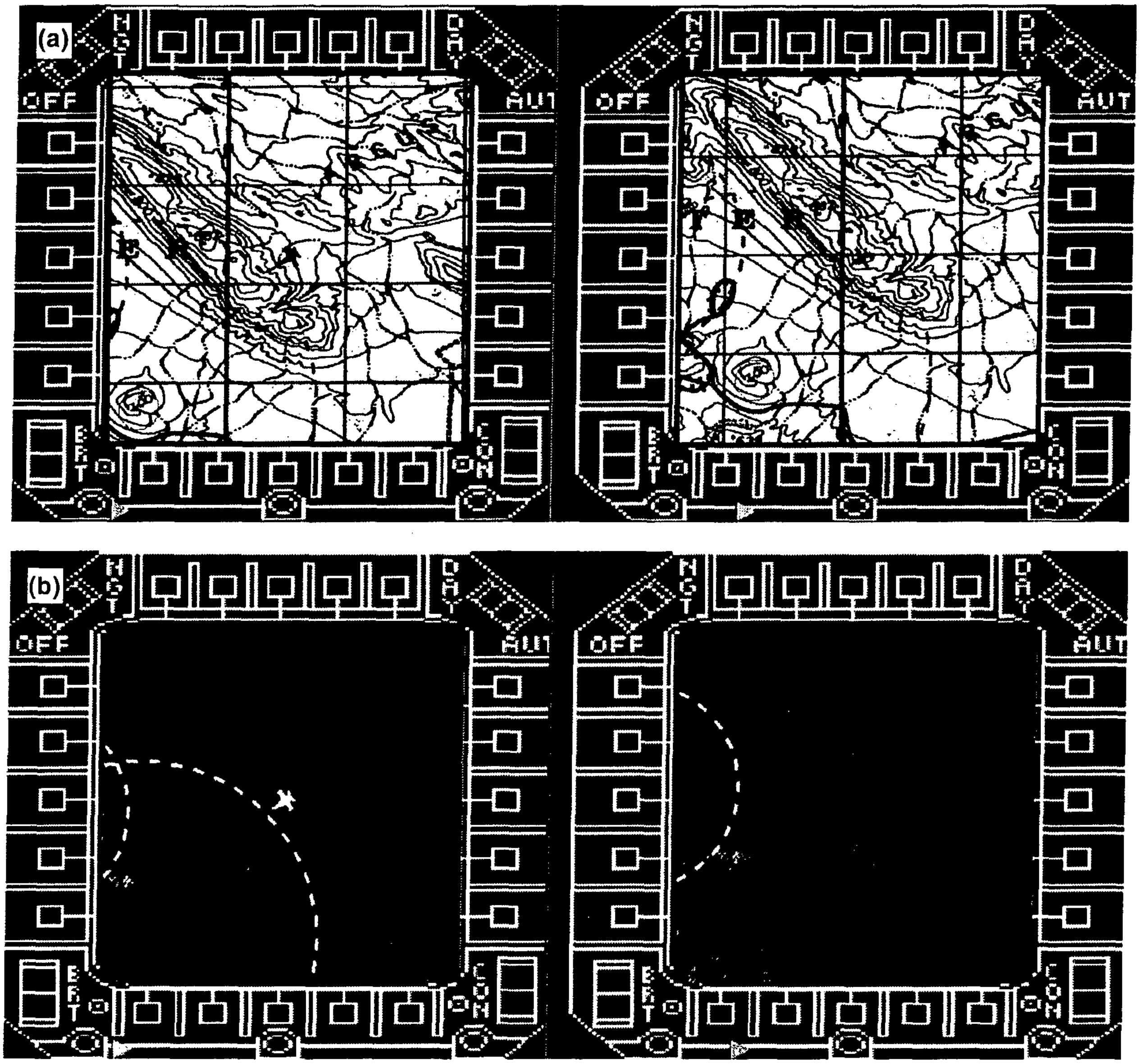

Fig. 27—Demo 15: threat rings (centered display, north-up, 2 nmi range), aircraft outside threat range (left-side plots) and inside range (right-side plots): (a) TLM-50 chart data and (b) SPOT satellite imagery

context, as well as the general difficulty in interpreting contour lines, negated some of the benefits of the HAT display that pilots noted in other views. Participants preferred the 3-D perspective view (a mesh grid) slightly over the 2-D contour lines as a base map for HAT.

Overall, many pilots noted that HAT would be extremely valuable for terrain avoidance, and a few commented that this was the single most useful feature they had seen in all of our map display demonstrations. HAT enhanced the base maps by boldly highlighting the most critical terrain elevations—those that were at or above the aircraft's current altitude.

Helicopter and tactical pilots rated CLOS *of considerable use* (average ratings 4.0 and 3.6, respectively), while Special Operations aircrew rated CLOS barely *of use* (2.7). These ratings

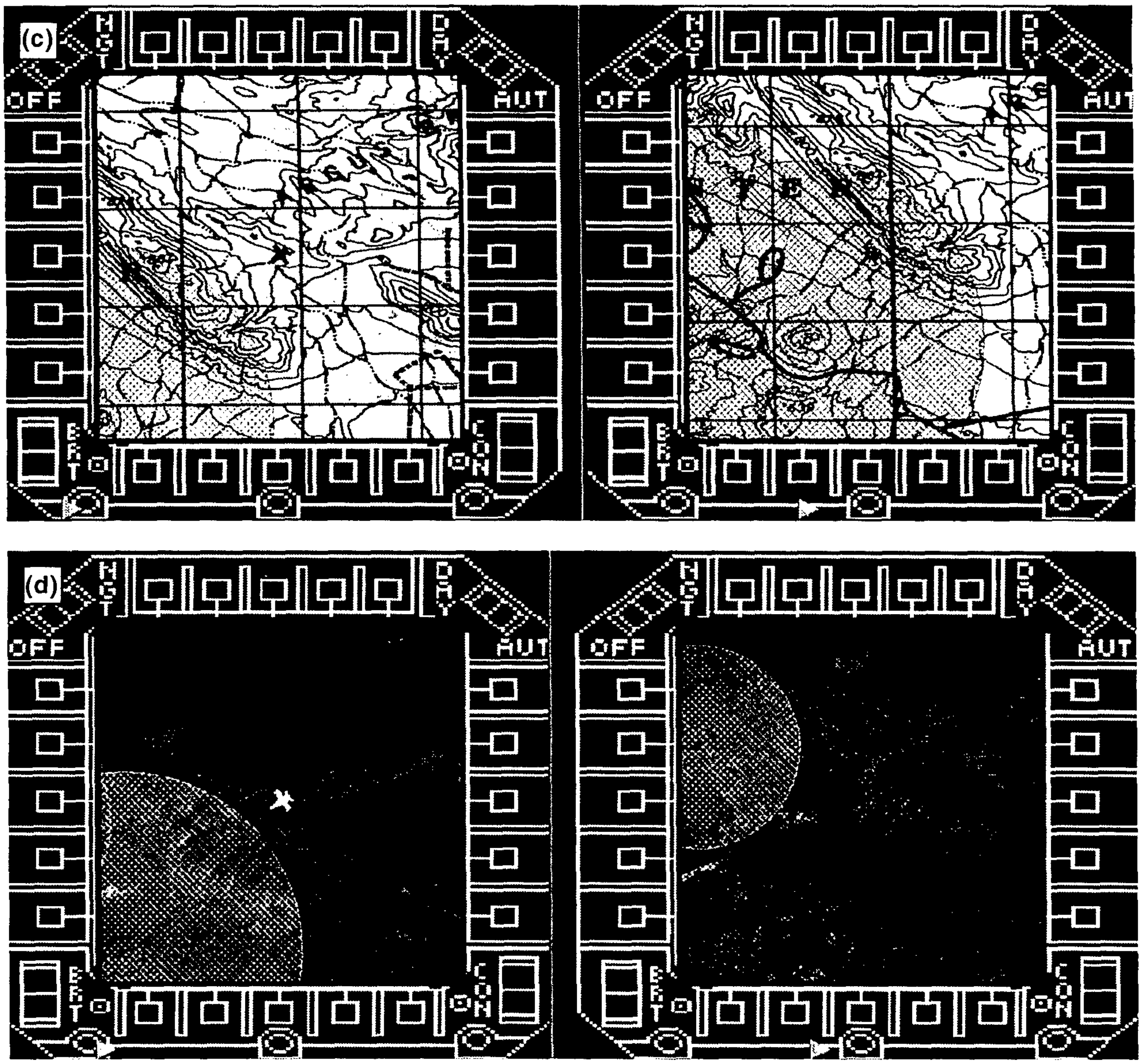

Fig. 27 — (cont.) pseudo-transparent hatched threat areas (centered display, north-up, 2 nmi range), aircraft outside threat range (left-side plots) and inside range (right-side plots): (c) TLM-50 chart data and (d) SPOT satellite imagery

probably reflect the relative importance of terrain information for each group's flight needs. Pilots' comments focused on the novelty of this display, despite similarities to an instrument approach plate. CLOS appeared to be most useful when specific information was required for terrain masking relative to a single target or threat.

Figure 29 reflects participants' preferences with respect to threat intervisibility displays. The results are split into two categories, according to the type of base map on which the threats were presented. In the first category, threat symbols were drawn over black-and-white satellite imagery; in the second category, the symbols were drawn over color aeronautical chart data.

For both categories, participants generally preferred the simplest representation—threat rings—because it obscured the least amount of the base map. Pilots reported that hatched areas and circles

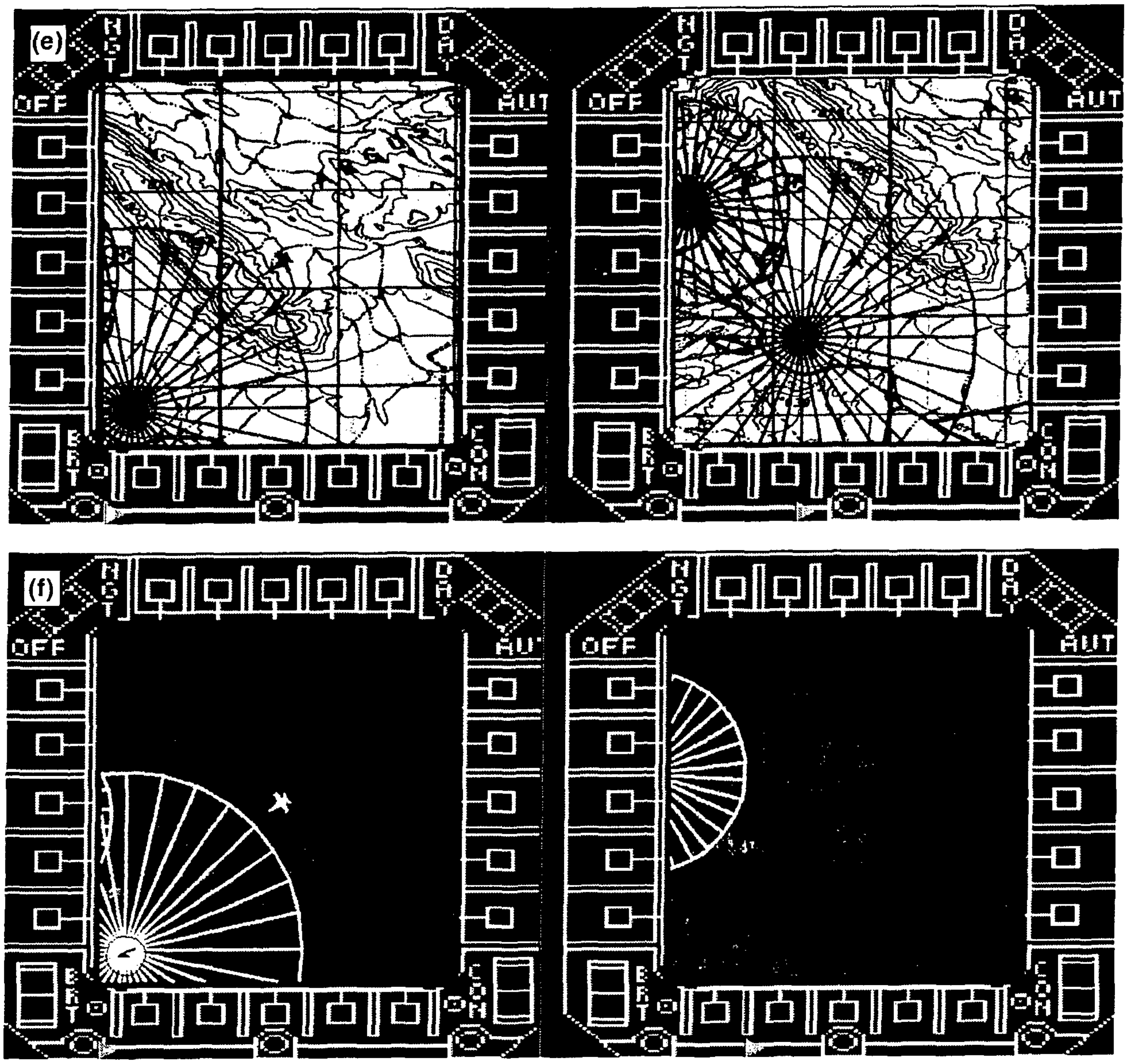

Fig. 27 — (cont.) threat rings with spokes (centered display, north-up, 2 nmi range), aircraft outside threat range (left-side plots) and inside range (right-side plots): (e) TLM-50 chart data and (f) SPOT satellite imagery

with spokes obscured too much underlying information in the threat area, while adding little additional information or warning of the threat, compared to open rings. We would have liked to test a true transparent threat overlay, which would have tinted the threat areas without obscuring them, but time constraints and technical limitations prevented such a test. When pilots were queried as to how they might respond to such a display, their reactions were mixed, and most participants maintained their preference for threat rings. However, a few commented that a simple circular ring was a poor model of the actual geographic distribution of the threat, and that aircraft speed and surrounding terrain should be taken into consideration.

In several of these demonstrations, the threat symbols and the aircraft cursor changed color from yellow to red when the simulated aircraft entered the threat area. Participants' reactions to this

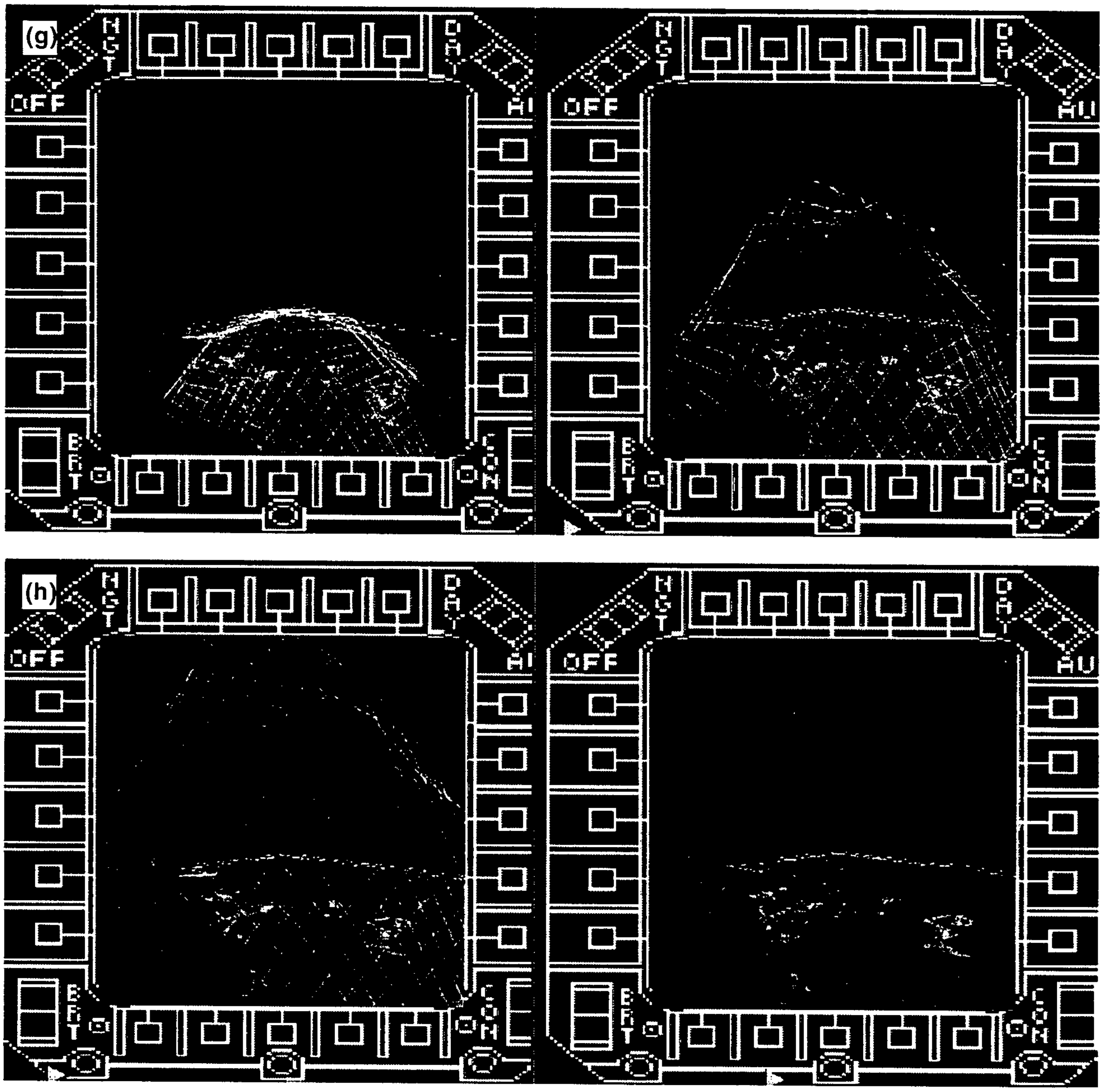

Fig. 27 — (cont.) 3-D threat dome over satellite imagery, in perspective display: (g) aircraft outside threat range, threat in sight (left) and approaching threat (right) and (h) aircraft entering the threat range, just outside threat range (left) and within range (right)

feature were mixed. Some pilots appreciated the additional cue that they were within the threat range, particularly when viewing a relatively large-scale map with only an edge of the threat ring visible. Other participants preferred simpler representations, with as few colors and display changes as possible.

In addition to standard 2-D views, participants viewed one 3-D representation of satellite imagery with a threat "dome" appearing above the terrain. The symbology was similar to the previous 2-D displays. Pilots' reactions were mixed, perhaps because of the novelty of the display or limitations of the computer graphics that were used to depict movement into the threat dome.

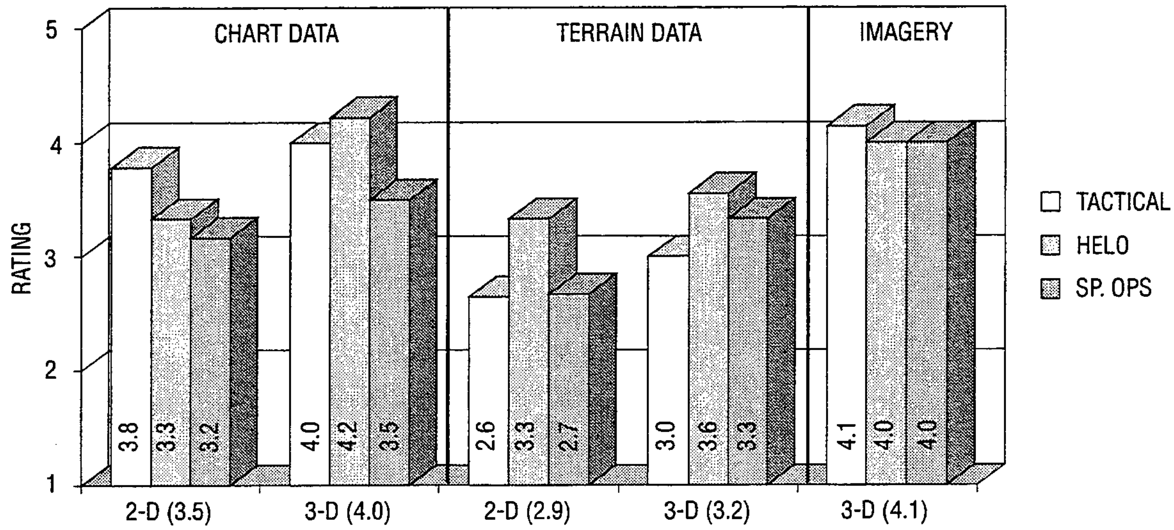

Fig. 28 — Ratings of HAT models over different base maps (Demo #13)

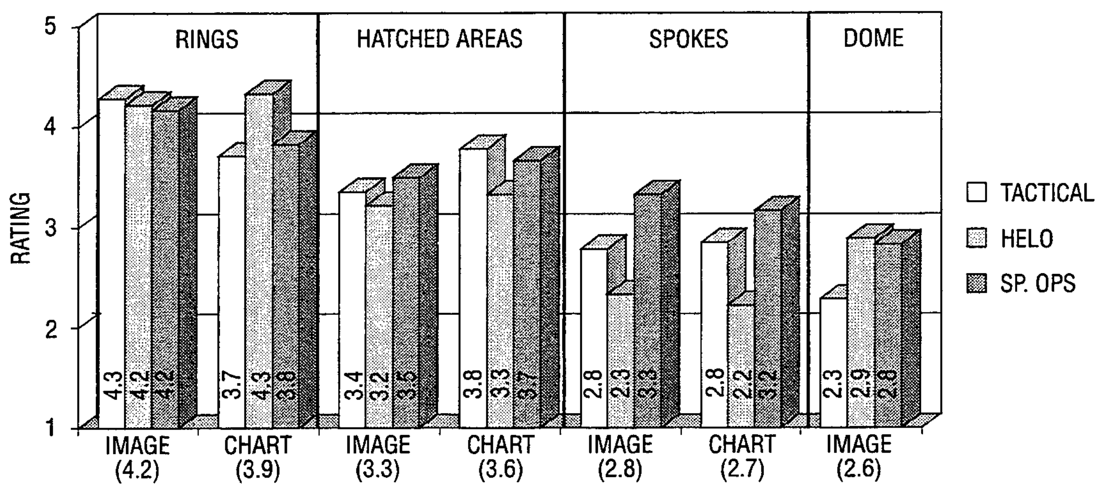

Fig. 29 — Ratings of threat symbology over satellite imagery and scanned chart data

Many commented that this 3-D view was difficult to interpret, and they could not tell when they had actually entered the dome, or once inside, how best to exit. Several commented that a 3-D threat representation would be very helpful in mission planning, but not in the cockpit.

The use of satellite imagery as a base map was novel to most participants, since it is not used in current Navy aircraft moving map displays, yet it produced a generally favorable response. In particular, pilots preferred threat rings displayed over imagery to threats displayed over charts. This was reflected by the fact that most participants rated "rings over imagery" a 4 (*of considerable use*) or 5 (*extremely useful*), and no participant rated this representation less than 3 (*of use*). By comparison, fewer participants rated "rings over chart" a 4 or 5, and two pilots rated this a 2 (*not very useful*). This is probably due to the fact that colored symbols over black-and-white imagery provide greater contrast than the same symbols over multicolored charts. The symbology and colors of the threat rings often confused or obscured chart symbology, but they stood out well against the monochrome satellite imagery.

4.5.3 Summary and Recommendations

Many pilots in the survey considered HAT to be a very useful enhancement to standard electronic charts, but not all participants agreed. Because of this disparity, it is recommended that HAT be a user-selectable feature that can be turned on or off, depending on mission requirements. HAT enhances satellite imagery very effectively by adding relative altitude information to the display and providing a "quick-look" at the critical terrain surrounding the aircraft. Overlaid on contour lines, however, HAT does little to aid an already difficult-to-interpret design.

Average ratings by both tactical and helicopter pilots indicated that CLOS would be *of considerable use* for their applications (3.6 and 4.0, respectively). The CLOS model appealed most to helicopter pilots, probably due to its utility in determining terrain masking from threats and targets. Therefore, including this feature for helicopters and other aircraft that would benefit from advanced terrain masking capabilities is recommended.

"Rings only" encapsulates most participants' preferences for threat symbology. While there were considerable rating differences among the other three threat symbols, depending on pilot categories (i.e., Tactical, Helicopter, Special Operations), nearly all participants rated rings highly. Also, many pilots preferred imagery to charts for threat overlays, probably because of fewer visual conflicts in the display. The 3-D representation (threat "dome"), as presented, was not judged to be of much benefit to pilots. A more sophisticated rendering of the 3-D dome might produce more favorable responses, however.

4.6 Vector Moving Map Displays

4.6.1 Description

Demo #16: Vector Moving Map Display: This demonstration depicted vector charts that included many of the cartographic features seen in previously demonstrated aeronautical charts. Vector maps are rendered from individually stored objects, including lines (e.g., roads), points with associated symbols (e.g., airports), text features (e.g., city names), and areas (e.g., shaded metropolitan areas or tinted areas of constant elevation). In contrast, the charts shown in previous demonstrations were scanned in their entirety from paper products, so individual cartographic features were not individually accessible or manipulable.

Participants were asked to evaluate three potential benefits of a vector map display: (1) the ability to keep text upright as the aircraft turned (while the map rotated in a track-up orientation, as shown in Fig. 30); (2) the ability to declutter the display after zooming out to a lower resolution, effectively decreasing the chart scale (Fig. 31a–c); and (3) the converse of declutter—adding detail to the display after zooming in to a higher resolution (effectively increasing the chart scale).

4.6.2 Results

When asked to assess their prior experience with vector-type map displays, 25 out of 30 participants said they had limited or no experience with this type of map. Nevertheless, 24 out of 30 participants considered the demonstrated vector map to be easily interpretable, and nearly all participants rated the three featured capabilities (keeping text upright, selectively decluttering, and

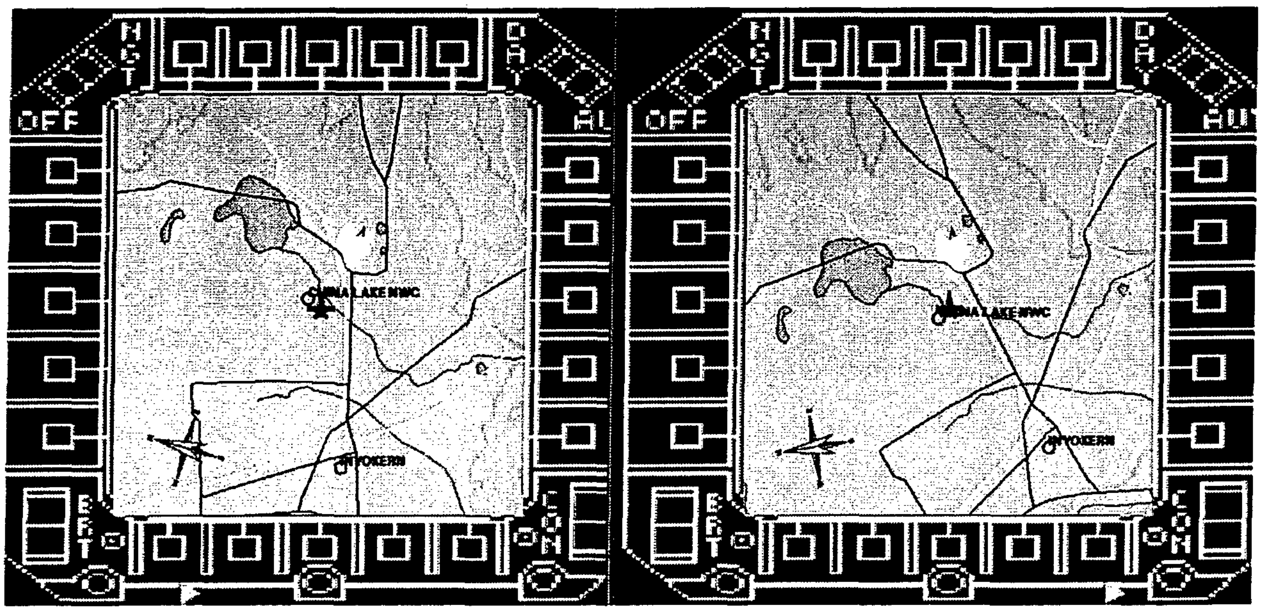

Fig. 30 — Demo 16: evaluating capability of vector moving map to display text upright in track-up mode (centered display, track-up, 20 nmi range): aircraft heading northeast (left) and heading southeast (right)

adding detail) very highly, as shown in Fig. 32. No pilot rated any of these features less than 3 (*of use*) and virtually all helicopter pilots gave all three capabilities the highest possible rating (*extremely useful*).

When asked specifically what map details they would want to add to this type of display, participants gave a wide variety of responses—from navigational information and terrain data to obstacle indications. No single type of information was predominant in their requests.

4.6.3 Summary and Recommendations

Based on pilot responses, vector-type maps clearly have potential for improving pilot performance. Keeping text upright in a track-up orientation and selective decluttering are clear advantages over current systems. Almost all pilots wanted to have a choice between manually decluttering the map and using an automatic declutter mode to remove extraneous details. Additionally, if vector maps were integrated into mission planning, the result may be a superior method for displaying spatial information and improving SA.

Many studies have linked display complexity to pilot performance, especially in terms of the pilot's ability to absorb and utilize the displayed information (e.g., Aretz 1988; Schons and Wickens 1993; Wickens and Carswell 1995). The last two reports found that visual clutter can disrupt the pilot's visual attention, resulting in greater uncertainty concerning target location. Therefore, a vector-based map display with declutter capabilities should be a significant improvement over the current, relatively static, raster map displays.

However, there are two potential obstacles to effectively implementing vector-based maps. The first is pilot training, since the customized quality of vector maps inevitably make them look different from standard aeronautical charts. In effect, pilots must acquire new cartographic skills to assist them in configuring their maps for specific mission requirements. The second obstacle

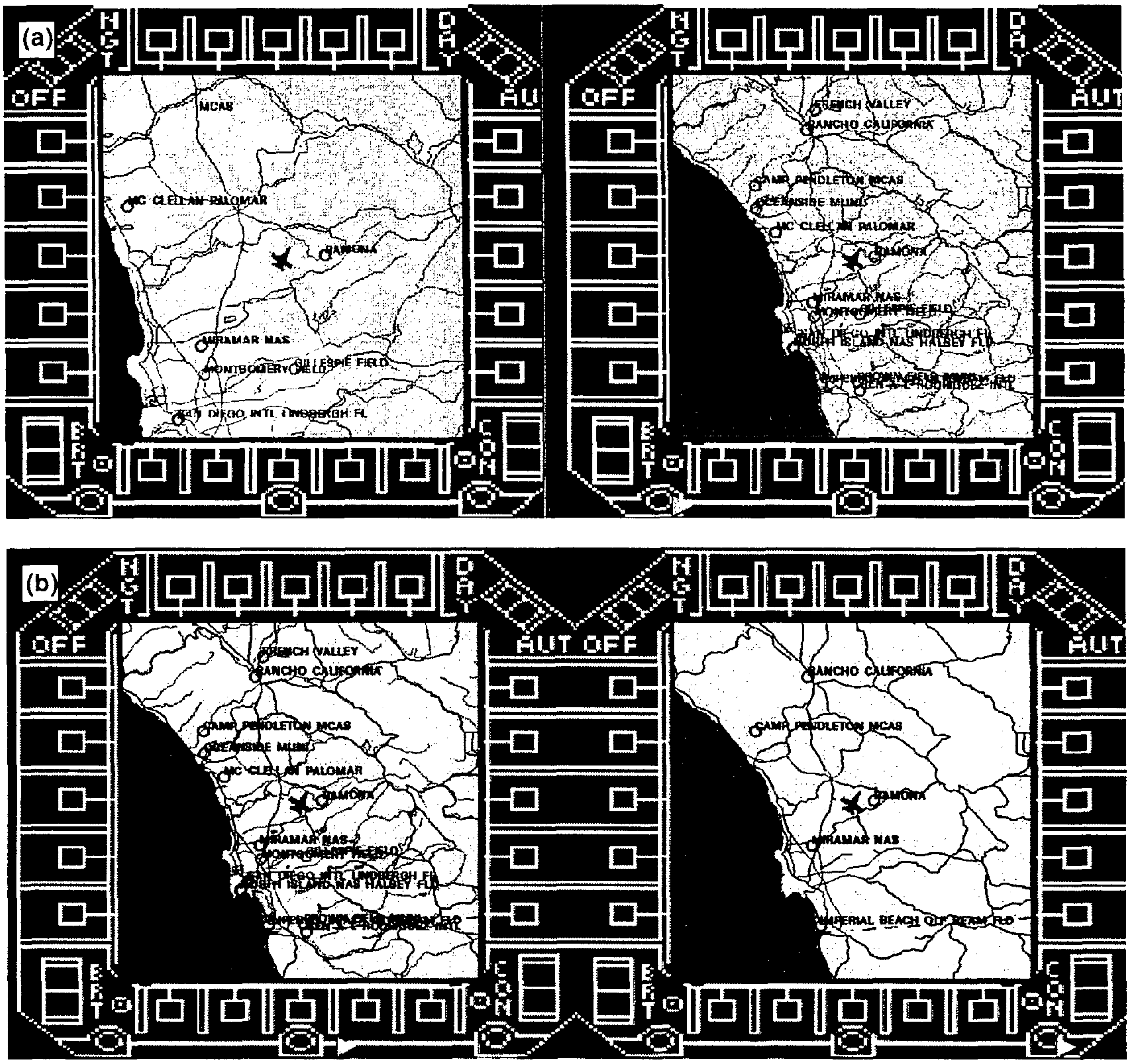

Fig. 31—Demo 16: centered display, north-up: (a) increased clutter during zoom-out, 20 nmi range, before zoom-out (left) and 40 nmi range after 2:1 zoom-out (right); (b) declutter capability of vector maps (e.g., removing terrain elevation contours), after initial declutter (left) and after removing rivers and some text (right)

to implementing vector maps in the cockpit is technical, since many cartographic options will have to be handled by the map display system to avoid overburdening the pilot. While storage and display limitations are rapidly being overcome by advances in computer technology, the problems associated with computer-aided cartography are still numerous. Automated cartography is a complex science still in its infancy, and automatically generated maps often lack the visual quality of maps created manually by trained cartographers. Further basic research in this area is sorely needed.

Clearly, vector map technology should be pursued for advanced mission planning and cockpit displays. Implementation of this technology should be carefully tested to ensure optimal pilot performance and enhanced mission success.

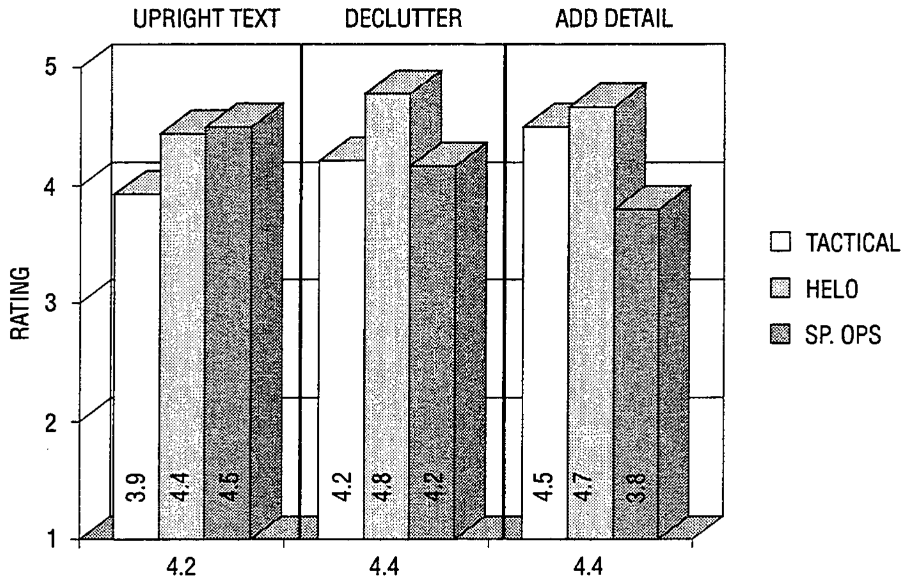

Fig. 32 — Ratings of demonstrated vector map functions

5.0 SUMMARY

Map designers who will develop advanced maps for electronic cockpit displays must weigh the benefits of cartographic flexibility against pilot workload. Pilots are already overwhelmed by an abundance of information from numerous cockpit displays, electronic or otherwise. A cockpit map system must be capable of conveying critical information concerning navigation, threats, and targets in a manner that is easily interpretable under often stressful conditions. Our recommendations concerning specific map data types and presentations are provided throughout this paper, under each demonstration category heading.

This study only measured pilot and aircrew preferences, not actual performance, with respect to the various map presentations. Other studies have shown significant discrepancies between subjective preference ratings and performance measures; often, subjects do not prefer the display that produced the best performance (e.g., Merwin and Wickens 1993). Therefore, we highly recommend that these pilot preference results be used in conjunction with flight performance tests in realistic flight simulators to ensure optimal pilot performance prior to the development and implementation of a new map display system.

6.0 ACKNOWLEDGMENTS

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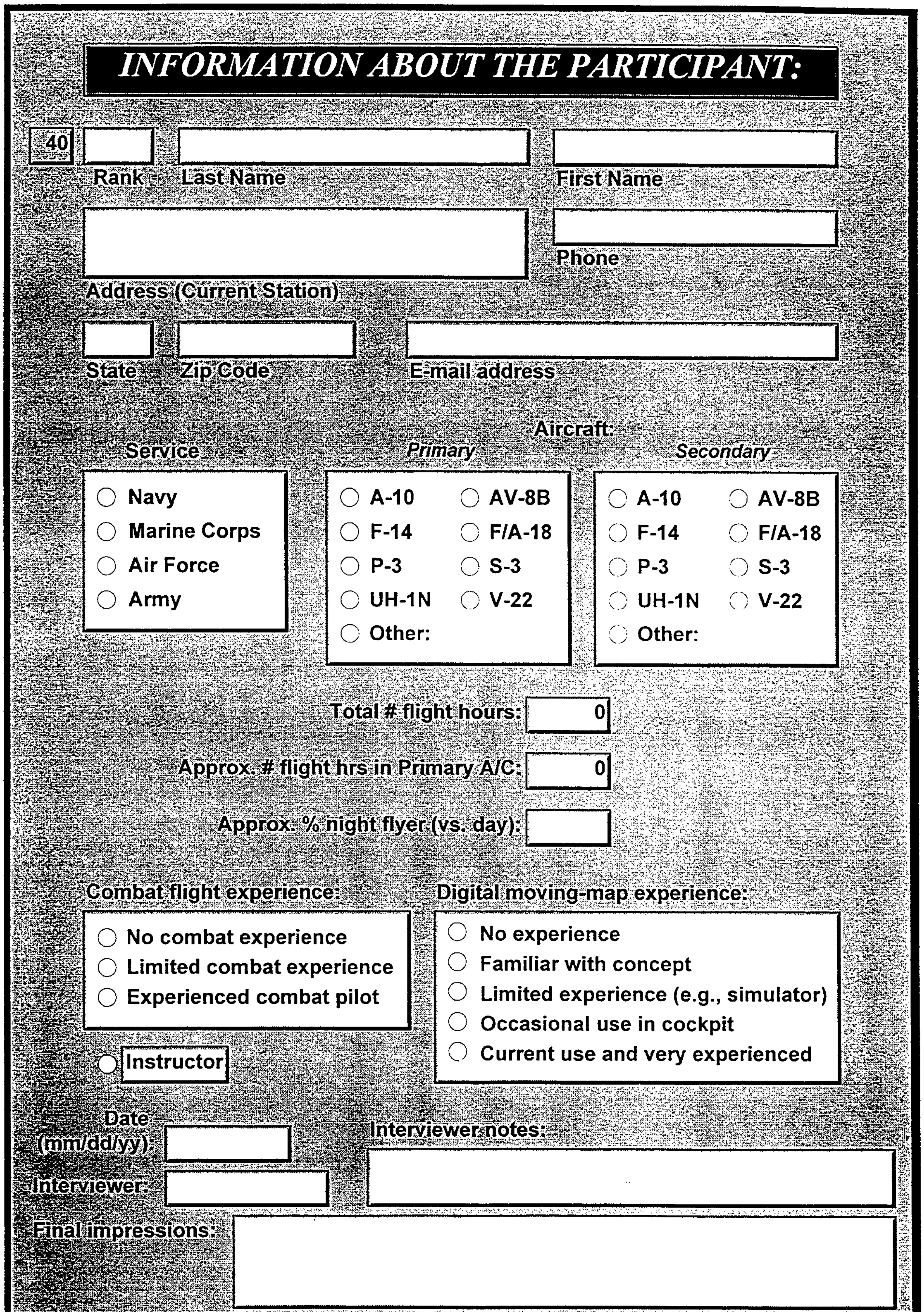
Appendix A

SAMPLE QUESTIONNAIRE



INFORMATION ABOUT THE PARTICIPANT:

40

Rank | Last Name | First Name

Address (Current Station) | Phone

State | Zip Code | E-mail address

Service

- Navy
- Marine Corps
- Air Force
- Army

Aircraft:

Primary

- A-10
- AV-8B
- F-14
- F/A-18
- P-3
- S-3
- UH-1N
- V-22
- Other:

Secondary

- A-10
- AV-8B
- F-14
- F/A-18
- P-3
- S-3
- UH-1N
- V-22
- Other:

Total # flight hours: 0

Approx. # flight hrs in Primary A/C: 0

Approx. % night flyer (vs. day):

Combat flight experience:

- No combat experience
- Limited combat experience
- Experienced combat pilot

Instructor

Digital moving-map experience:

- No experience
- Familiar with concept
- Limited experience (e.g., simulator)
- Occasional use in cockpit
- Current use and very experienced

Date (mm/dd/yy):

Interviewer:

Interviewer notes:

Final impressions:

TIME TO SWITCH MAP MODES

Demonstrating the amount of time to switch between map modes. The display switches from a chart to satellite imagery to terrain elevation to a data frame (in this case, a reconnaisance photograph). Each switch is timed from a simulated pilot request until the display changes.

Note: to simulate the amount of time to perform the switch, the display turns black when the request is made, and returns to its original color when the change is implemented.

Indicate in the chart below which switch times (A, B, and / or C) would be satisfactory for your applications, or if NONE of them would be satisfactory:

- ○ Time A
- ○ Time B
- ○ Time C
- ○ None

Rate the demonstrated map modes (data types) on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
Chart data:	○	○	○	○	○
Satellite imagery:	○	○	○	○	○
Terrain elevations:	○	○	○	○	○
Data frames:	○	○	○	○	○

TIME TO SWITCH SCALES

Demonstrating the amount of time to switch between chart scales. The display switches from JOG (~10 nmi range) to TPC (~20 nmi) and back to JOG. Each switch is timed from a simulated pilot request until the display changes.

Note: to simulate the amount of time to perform the switch, the display turns black when the request is made, and returns to its original color when the change is implemented.

Indicate in the chart below which switch times (A, B, and / or C) would be satisfactory for your applications, or if NONE of them would be satisfactory:

- ○ Time A
- ○ Time B
- ○ Time C
- ○ None

COMMAND LAT / LON REPOSITION

Demonstrating the amount of time to switch from a moving chart to a specific latitude / longitude position outside the current display range. Each switch is timed from a simulated pilot request until the display changes.

Note: to simulate the amount of time to perform the switch, the display turns black when the request is made and returns to its original color when the change is implemented.

Indicate in the chart below which switch times (A, B, and / or C) would be satisfactory for your applications, or if NONE of them would be satisfactory:

- ○ Time A
- ○ Time B
- ○ Time C
- ○ None

DISPLAY UPDATE RATES

Comparing two different display update rates for varying aircraft speeds and degrees of bank. For each display update rate, speeds are simulated at 0, 90, 200, and 300 kts. All turn rates are simulated at 7deg / sec, and the resulting degrees of bank are shown. All views are JOG (~10 nmi range / 1:250,000 scale) charts in track-up mode.

You will be shown two different display update rates ("A" and "B") for each airspeed. After viewing both update rates for a given airspeed, indicate in the chart below if update rate A and / or B was satisfactory for your applications, or if NEITHER was satisfactory:

	A	B	Neither
0 kts:	○	○	○
90 kts (30 deg bank):	○	○	○
200 kts (52 deg bank):	○	○	○
300 kts (62 deg bank):	○	○	○

If either update rate was NOT satisfactory for one or more of the demonstrated airspeeds, please explain why...

DECENTER POSITIONS

This demo shows 4 positions for the aircraft cursor in north-up and track-up modes.

Rate the demonstrated aircraft cursor positions on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

		1	2	3	4	5
North-up:	*centered in screen:*	○	○	○	○	○
	1/4 up from bottom:	○	○	○	○	○
	1/7 up from bottom:	○	○	○	○	○
	bottom of screen:	○	○	○	○	○
Track-up:	*centered in screen:*	○	○	○	○	○
	1/4 up from bottom:	○	○	○	○	○
	1/7 up from bottom:	○	○	○	○	○
	bottom of screen:	○	○	○	○	○

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

Comments re: your preferred options ...

☐ Would you want to be able to change your default decenter position (e.g., 86%) to another position (e.g., 100%)? Check box if "yes".

Why, or in what situations?

How would you prefer the default decentered position to be set for your map display?

- ○ Preset default / unalterable
- ○ Preset default / pilot-changable
- ○ Pilot selectable default
- ○ No preference

If you chose pilot-changable or selectable, where should this be set?

- ○ In mission planning only
- ○ In the cockpit only
- ○ In mission planning and cockpit
- ○ No preference

ZOOM vs. CHART SWITCHES

This demo shows the difference between zooming in on a chart and switching from one chart to another. It also shows every available chart series (except TLM-100, which was not available for China Lake).

Rate each of the demonstrated chart series on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

	1	2	3	4	5
GNC (1:5M):	○	○	○	○	○
JNC (1:2M):	○	○	○	○	○
ONC (1:1M):	○	○	○	○	○
TPC (1:500k):	○	○	○	○	○
JOG (1:250k):	○	○	○	○	○
TLM (1:50k):	○	○	○	○	○

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

Rate the usefulness of zooming within a chart series:

	1	2	3	4	5
Zooms within a chart series:	○	○	○	○	○

In what situations (if any) would zooming within a chart series be useful to you?

How would you want the computer to zoom within a chart series?

- ○ Only zoom up to scale of next chart series, then switch series (e.g., zoom a TPC by no more than 2:1, then switch to JOG)
- ○ Allow zooms beyond scale of next chart series
- ○ No preference

Which (if any) of the zoomed charts became too blocky or difficult to read?

○ GNC ○ JNC ○ ONC ○ TPC ○ JOG ○ TLM ○ none

STEPS TO ZOOM 2:1

Demonstrating three variations on a 2:1 zoom:

(1) zoom in a single step;
(2) zoom in 8 steps;
(3) "continuous" zoom.

All views are north-up, centered mode.

Rate each of the demonstrated zoom models on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
Zoom (2:1) in a single step:	○	○	○	○	○
Zoom (2:1) in 8 steps:	○	○	○	○	○
"Continuous" zoom (2:1):	○	○	○	○	○

Comments re: why any of these zooms would be more / less effective for you:

How would you like to see these zoom controls implemented (e.g., hold button down until reach desired zoom; press button for each zoom increment; press another button to return to original scale; etc ...)

ZOOM-OUT CAPABILITY

This model illustrates "zooming-out" from the display to show more range. Rate the demonstrated zoom-out model on a scale of 0 to 3 to reflect how useful YOU feel this would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
Zoom-out from chart:	○	○	○	○	○
Zoom-out from imagery:	○	○	○	○	○

In what situations (if any) would a zoom-out capability be useful to you?

SCALE / RANGE ISSUES

Demonstrating the difference in display range between current and next-generation chart displays (e.g., 20 nmi from top to bottom of screen for current TPC display vs. 15.2 nmi for future TPC; and 10 nmi for current JOG display vs. 7.6 nmi for future JOG). There is a trade-off between display range (nmi) and chart detail / legibility, which you are asked to evaluate.

Which TPC coverage provided the best range (coverage) for your applications?

- ○ Chart A
- ○ Chart B
- ○ No preference

Which TPC coverage provided the best detail / legibility for your applications?

- ○ Chart A
- ○ Chart B
- ○ No preference

Which JOG coverage provided the best range (coverage) for your applications?

- ○ Chart A
- ○ Chart B
- ○ No preference

Which JOG coverage provided the best detail / legibility for your applications?

- ○ Chart A
- ○ Chart B
- ○ No preference

Would you prefer a default (pre-zoom) display to show a chart with greater range (but less detail) or more detail (but less range)?

- ○ Greater range / less detail
- ○ More detail / smaller range
- ○ No preference

TERRAIN ELEVATION CONTOURS / SHADING

Demonstrating terrain elevations as contour lines vs. elevation shading.
Both planimetric (2-d) and perspective (3-d) views are shown.

Rate the demonstrated terrain elevation maps on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
Contour lines for 2-d terrain:	○	○	○	○	○
Contour lines for 3-d terrain:	○	○	○	○	○
Gray shading for 2-d terrain:	○	○	○	○	○
Gray shading for 3-d terrain:	○	○	○	○	○

Comments re: your preferences:

TERRAIN ELEVATION CONTOUR INTERVALS

Demonstrating terrain elevations (with HAT overlays) at different contour intervals. The equivalent chart scale for this demo is a JOG (10 nmi range from the top to the bottom of the display).

Rate the demonstrated terrain elevation contour intervals on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
Contour Interval A:	○	○	○	○	○
Contour Interval B:	○	○	○	○	○
Contour Interval C:	○	○	○	○	○
Contour Interval D:	○	○	○	○	○

SUN-ANGLE SHADING (2-D, 3-D)

Demonstrating realistic sun-angle shading over terrain elevations in 2-d and 3-d. Shading simulates the shadows over the ground for a specific time of day. Comparisons are made between different shading techniques (#gray levels) and different # of sun-angle steps for a whole day (sunrise to sunset).

Rate the demonstrated sun-angle shaded views (2-d and 3-d) on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = of NO use
2 = not very useful
3 = of use
4 = of considerable use
5 = extremely useful

	1	2	3	4	5
2-d sun angles:	○	○	○	○	○
3-d sun angles:	○	○	○	○	○

Briefly describe how sun angle shading would be useful to you ...

The 2-d movie demonstrated two different # gray levels for sun-angle shading. Which model would you prefer for your applications (A or B) ?

○ 2-d model A
○ 2-d model B
○ No preference

The 3-d movies demonstrated two different precisions of sun angle (i.e., the # steps used to simulate the sun's movement from sunrise to sunset). Which would you prefer for your applications (A or B) ?

○ 3-d movie A
○ 3-d movie B
○ No preference

HAT OVER CHART OR IMAGERY

Demonstrating Height Above Threshold (HAT) overlays on a moving map:
Yellow = all elevations at A/C altitude +/- 16 m; Red = all elevations above yellow.
HAT shown on chart, terrain, and imagery; in planimetric (2-d) and perspective (3-d).

	yes	no
Are 2 HAT bands / colors sufficient?	☐	☐
Are these HAT colors (yellow, red) OK?	☐	☐

If you answered "no" to either question, please comment (e.g., How many HAT bands would be sufficient? Which colors would you prefer? Why?)

Should users be able to select their own HAT colors?

- ○ No
- ○ Yes (in mission planning only)
- ○ Yes (in mission planning or in the cockpit)

Rate the demonstrated HAT models on a scale of 1 to 5, to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
HAT over 2-d chart:	○	○	○	○	○
HAT over 3-d chart:	○	○	○	○	○
HAT over 3-d terrain:	○	○	○	○	○
HAT over 2-d terrain:	○	○	○	○	○
HAT over 3-d imagery:	○	○	○	○	○
HAT over 2-d imagery:	○	○	○	○	○

How might you use this information (HAT overlays) ...

CLOS OVER IMAGERY (2-D, 3-D)

Demonstrating Clear Line of Sight (CLOS) over planimetric (2-d) imagery in one display window, with a perspective (3-d) profile view of CLOS displayed in a second window. All views are track-up, centered mode.

Rate the demonstrated CLOS model on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
2-d imagery with 3-d CLOS profile:	○	○	○	○	○

Briefly describe how you might use the information presented in this model ...

THREAT INTERVISIBILITY

Demonstrating threat intervisibility in 2-d (threat rings, spokes, and transparent color overlays) and 3-d (domes). Color of overlay (rings, spokes, etc) changes from yellow to red as aircraft enters "danger zone". All views are north-up, centered mode. Sequence is demonstrated for satellite imagery and chart data.

Rate each of the demonstrated models of threat intervisibility on a scale of 1 to 5 to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

Imagery

	1	2	3	4	5
2-d threat rings:	○	○	○	○	○
2-d threat areas:	○	○	○	○	○
2-d threat spokes:	○	○	○	○	○
3-d threat domes:	○	○	○	○	○

Chart

	1	2	3	4	5
2-d threat rings:	○	○	○	○	○
2-d threat areas:	○	○	○	○	○
2-d threat spokes:	○	○	○	○	○
3-d threat domes:	○	○	○	○	○

Can you suggest any better representations of threat intervisibility? If so, please describe ...

Comments re: how you might use this information (threat overlays) in 2-d view:

Comments re: how you might use this information in 3-d view:

VECTOR MAP DISPLAY

*** NOTE: THIS SURVEY INCLUDES 2 PAGES !

Demonstrating vector map capabilities (combining user-selected layers of map data). Demo includes 2-d and 3-d views and illustrates the unique capabilities of vector maps, as compared to the current raster scanned charts.

Have you had any experience with vector map displays, similar to this?

- ○ No experience
- ○ Familiar with concept
- ○ Limited experience
- ○ Occasional use
- ○ Very experienced

How easily could you interpret the information in this map display?

- ○ I could not understand it at all
- ○ I could interpret the map with some difficulty
- ○ I could easily interpret the map

Rate the usefulness of the following vector map capabilities on a scale of 1 to 5, to reflect how useful YOU feel each would be for YOUR map display needs:

1 = Of no use
2 = Not very useful
3 = Of use
4 = Of considerable use
5 = Extremely useful

	1	2	3	4	5
Display upright text on track-up map:	○	○	○	○	○
Declutter (e.g., for zoom-outs):	○	○	○	○	○
Selectively add map details:	○	○	○	○	○
2-d vector map with HAT overlays:	○	○	○	○	○
3-d vector map with HAT overlays:	○	○	○	○	○

How do you think decluttering should be implemented?

- ○ Automatically (based on zoom factor and preset priorities
- ○ Manually (pilot-selectable)
- ○ Choice between automatic / manual declutter modes

If you could selectively add or remove certain chart features on the displays that you currently use, what specific features would you want to add? remove? modify? keep (as is)?

Comments regarding how you might use this type of vector map display:

Appendix B

HUMAN FACTORS MATRIX OF DIGITAL MAP DATA REQUIREMENTS

APPENDIX B. MATRIX OF MOVING-MAP ISSUES ADDRESSED BY NRL STUDY

#	Name	Description	Demo #(s)	Preliminary program specifications: TAMM	ASQ196	F/A-18	AV-8B	V-22	UH-1N
1	Data update rate	Rate that data is updated on display. 20 Hz = 20x / sec (50 msec).	4	20 Hz				15 Hz	
6	Scale changes: time	Time to change current displayed area to different, existing scale.	2						<=1 sec
7	Needed scales?	1:50k, 1:100k, 1:250k, 1:500k, 1:1M, 1:2M, 1:5M, CIB (1:50k)	6						
8	Change CADRG <-> CIB	Change from CADRG to CIB imagery and vice versa.	1					<=1 sec	<=3 sec
10	Change map mode	1) CADRG 2) DTED 3) CIB 4) Data frame	1,13, 15						
11	Change map mode: time	Time to change between modes listed in item #10.	1					<=1 sec	<=3 sec
15	Threat intervis.: type	Spokes vs. translucent color blobs (envelope)?	15						
16	Update CLOS: time	Calculated line-of-sight (intervisibility between any 2 points).	14						<= 1 sec
19	Threat overlay updates	Ability of threat overlays to display in correct position as map moves.	13,14,15	<=50 ms					

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24	HAT display	Height above Terrain / Threshold / Target / Touchdown	10,13		6 bands		3 bands	6 bands	
27	Zoom display	Is 2-to-1 adequate? New scale auto / manual? Fixed / variable zoom ctrl?	6,7,8,9,16					<=500 ms	<=1 sec
28	Zoom method	Zoom in discrete steps or continuously variable?	6,7,8	8 steps					
29	Declutter overlays	Remove user-spec'd overlays / items / background? User-spec declutter modes?	16						<=1 sec
31	Center/Decenter display	Move map so own-position close to bottom (in track-up).	5	75%	~100%			86%	75%
32	Command lat/lon repos'n	Time for map to move to user-selected lat / lon (in or out of current displayed area).	3						<=1 sec
35	DTED w/ sun shading	How long to display DTED with sun- or moon- angle shading?	12					<=2 sec	
36	Update sun/moon-angle	Can shading keep up w/ sun movement? Can it keep up with map movement?	12					<=2 sec	<=2 sec
37	Deg. incr. for sun-angles	What degree increments needed for DTED sun/moon-angle shading?	12	15 deg				1 deg	
38	Gray scales for sun-angle	How many gray scales required for DTED sun/moon-angle shading?	12					15	

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39	Display data frame: time	Display data frame and turn to true azimuth.	1					<=1 sec	
41	Planimetric view req'ts	What info is needed on planimetric view?	Many						
42	Perspective view req'ts	What info is needed on perspective view? How to display?	12-15, 17						
43	Contours / Shading	When to use contour lines, when to use elev'n shading?	10,11	100 ft				16-128 m	
44	Symbology	What symbol set to use for displays?	Many	ASQ196					